THE GEOLOGICAL HISTORY

OF THE

RIVERS OF EAST YORKSHIRE

BEING THE SEDGWICK PRIZE ESSAY
FOR THE YEAR 1900.

BY

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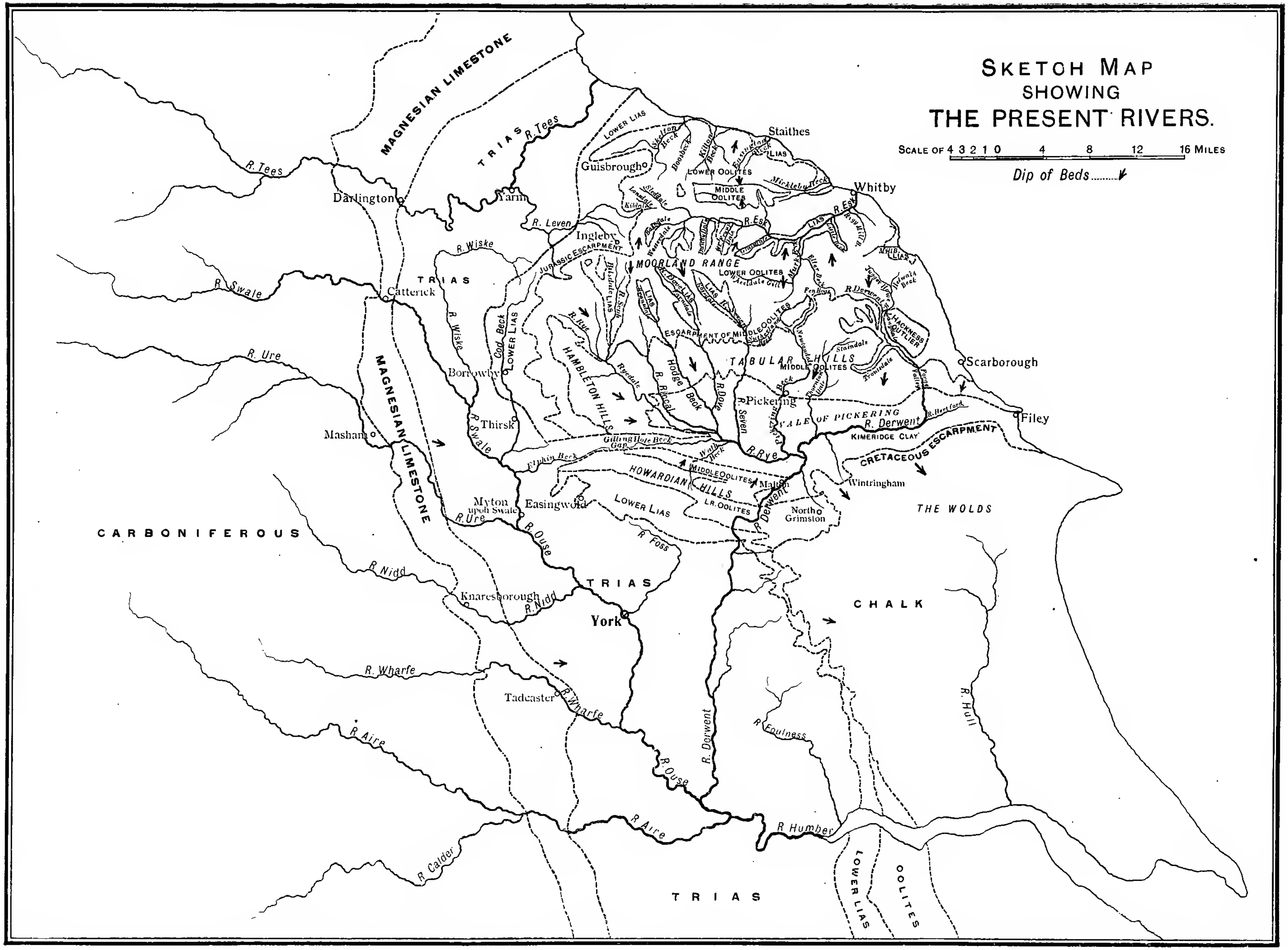

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PREFACE.

THE study of the dependence of the water-courses of a country upon its geological structure has of recent years attracted so much attention, especially in America, that the selection of this subject for the Sedgwick Essay for 1900, with the stipulation that the area should be British, was a distinct recognition of the opportunities afforded for this branch of geological enquiry in the British Isles, and a direct encouragement to the pursuit of a line of investigation which has been somewhat neglected at home.

East Yorkshire appeared to the author of the following Essay to offer an exceptionally favourable field for such a study: firstly, on account of the variety of its geological formations with important lithological differences; secondly, on account of its peculiar tectonic characters; and thirdly, on account of the abundant development of streams and rivers on its surface.

The minute knowledge which we possess of its stratigraphy and geological history was recognised as providing special facilities for such research.

The author is indebted to the writings of many geologists for the account of the stratigraphy and structure of the district, but primarily to the Memoirs of the Geological Survey.

With regard to the history of the rivers the work of Mr C. Fox-Strangways has been found particularly suggestive and helpful, especially in connection with the post-glacial adjustments of the streams.

The theory of consequent and subsequent rivers in the East of England, which has proved of fundamental value, is derived from Prof. W. M. Davis's article published in the *Geographical Journal* for 1895 (vol. v. p. 127); and the application of this theory in its minor details has been greatly assisted by the study of the numerous works by American and Continental writers which treat of the evolution of river-systems.

CONTENTS.

INTRODUCTION.

DURING the last few decades it has become generally recognised that the present drainage-system of any region is the result of a gradual process of evolution, and worthy of the careful study of the geologist.

The process of evolution may have been long or short, regularly and uninterruptedly continued from its initiation down to the present time, or intermittent and broken up into several more or less distinct stages.

The interpretation of the characteristics and peculiarities of a drainage-system must therefore be sought for in the geological history and structure of the area over which it is spread.

Accordingly, in commencing the study of "*the dependence of the water-courses of a region upon its geological structure,*" we must obtain a knowledge of the rocks which compose that region, of the changes through which it has passed in the course of geological ages, of the earth-movements which have affected it, of the resulting geological structure, and of the present topography and distribution of the rivers.

The earliest period at which a land-surface was there formed, and the characters and geological structure of this "constructional surface" are important points which require to be investigated before we may attempt to trace the initial water-courses which drained it. Its whole subsequent history must then be followed, special attention being paid to the influence of the various periods of movement (elevation or depression), and of sedimentation or denudation, upon the normal progress of river-development.

In proportion as the process of evolution has been long and complicated, so will the interpretation of the relations of the present rivers to the geological structure be more beset with difficulties.

The region which is here selected for study consists of the north and north-eastern portions of Yorkshire, and nearly corresponds to the area embraced by the North Riding. Our attention will, however, be principally directed to the eastern part lying between the Tees and the Yorkshire Wolds, as the dependence of the water-courses on the geological structure is exhibited here with particular clearness.

It has been somewhat the habit to discuss the rivers of the north-eastern highlands of Yorkshire apart from those of the adjoining districts, and as if they had had an independent origin and separate history. But this method of treatment appears to me to be erroneous in principle and misleading in results, since the geological history of one limited area cannot be naturally dissociated from that of the surrounding districts, as Prof. W. M. Davis (1) has brought out with great clearness in his important essay on the "Development of certain English Rivers."

Accordingly, it will frequently be found necessary to take into account the evidence from adjoining areas, and it is desirable at the outset to give a sketch of the drainage of the eastern slopes of the county of Yorkshire as a whole before proceeding to concentrate our attention on a limited portion of it.

CHAPTER I.

GENERAL CHARACTERS OF EAST YORKSHIRE AND ITS RELATIONS TO SURROUNDING DISTRICTS.

THE north-western portion of Yorkshire is a mountainous district of Palæozoic rocks, rising from 1500 to over 2000 feet in height, and forming part of the Pennine Chain which stretches from north to south. It is the principal watershed of the county; the Tees, Swale, Ure, Nidd, Wharfe and Aire rise in it, and flow in an easterly or south-easterly direction to the Vale of York, to which the surface of the country slopes gradually down, the Carboniferous beds which compose the ground having a general dip also in the same direction.

The Vale or Plain of York forms part of the long belt of low-lying ground which reaches from the mouth of the Tees to the valley of the Humber, and varies in breadth from 8 to 30 miles while it rarely rises to more than 200 feet above sea-level in small undulations and hills. It corresponds practically with the outcrop of the soft Triassic marls and sandstones, but is largely overspread with glacial and alluvial deposits. It is bounded on the west by the outcrop of the Magnesian Limestone, and on the east by the Jurassic escarpment.

The Ouse which is the main river of this part of Yorkshire flows southwards along the greater portion of this valley, and by its tributaries receives nearly all the drainage of the western highlands, ultimately discharging itself into the Humber.

The northern end of this long stretch of low ground drains to the north-east, being traversed by the lower portion of the

Tees which is here separated from some of the headwaters of the Ouse by an inconspicuous low watershed in the middle of the Triassic plain.

Between this plain and the North Sea there rises the elevated mass of ground called the Eastern Moorlands, connected with the Yorkshire Wolds in the south by the curved ridge known as the Howardian Hills.

The Eastern Moorlands, comprising the Cleveland Hills, the Hambleton Hills, and the so-called Moorland and Tabular Ranges, consist of Jurassic beds, and with the Howardian Hills of similar composition form a long escarpment overlooking the Plain of York, and rising in parts to a height of over 1000 feet. At its southern end this escarpment joins the Cretaceous escarpment of the Yorkshire Wolds which stretches away down to the Humber and is breached by it.

The high ground forming the Eastern Moorlands has an elevation varying from 500 to 1500 feet above sea-level; the greater altitudes are found towards its western border, and there is a general decrease in height towards the east.

On the south the ground falls away gradually into the low-lying area which is known as the Vale of Pickering, and which is a long oval-shaped depression extending east and west for nearly 30 miles and with a width of from 5 to 10 miles. It consists principally of Kimeridge Clay, but superficial deposits attain a considerable thickness over most parts of it. Its surface is mostly less than 100 feet above sea-level, the eastern part being flatter than the western which is diversified by a few small hills and ridges. On the north and west it is bounded by the Tabular and Howardian Hills of older Jurassic beds; on the south is the northern Cretaceous escarpment of the Wolds, while the narrow eastern end is open to the sea though much blocked by drift. The Vale of Pickering is one of the most remarkable features of the whole region.

The present drainage of all the country east of the Plain of York, or Central Valley as it may conveniently be termed, is almost independent of that to the west of it. In the north the river Leven which flows into the Tees is the only stream of any importance which flows westwards. In the south the river

Derwent which collects in the Vale of Pickering all the drainage of the southern slopes of the Moorlands, breaks through the barrier of the Howardian Hills at Malton and flows southwards at the foot of the Cretaceous escarpment. It has often been remarked that its natural course seems directly eastwards along the Vale of Pickering into the sea near Filey.

The northern part of the Eastern Moorlands (with the exception of a few small streams running northwards straight into the sea) is drained by the Esk which has a general easterly course to the sea at Whitby. All the rivers from the northern dales of the Moorlands flow northwards into it, while those from the southern dales flow southwards into the Derwent in the Vale of Pickering, as above mentioned.

The Yorkshire Wolds, which consist of Cretaceous rocks, rise to a height of from 500 to 800 feet along the southern side of the Vale of Pickering. The general slope of their surface is to the south or south-east, and their drainage is almost entirely effected by the river Hull which flows southwards into the Humber. The great Wold Valley from Settrington near Malton to Bridlington on the coast is an important physical feature though not now occupied by a perennial stream.

From the foregoing general remarks it will have been observed that the general slope of the eastern half of Yorkshire is on the whole to the east and south-east, though its continuity is interrupted by the depression of the Central Valley. It will also have been noticed that it is split up into several distinct catchment-areas, each draining in a different direction by independent river-systems. Such are the Tees, the Ouse, the Esk, the Hull, and the Derwent river-systems.

With regard to the general elevation of the country the surface of the ground is found to rise on the whole from the south to the north, though in a less marked manner than from the east to the west.

Thus from Burton Head in the Eastern Moorlands to Mickle Fell in the west there is a rise of 1115 feet, while from Wilton Beacon on the Wolds to Burton Head there is a rise of only 680 feet. Phillips (2) long ago drew attention to these

facts and insisted on their importance with regard to the physical geography of the district.

As Prof. W. M. Davis (1) has pointed out, it cannot fail to be observed that with the exception of the stream in the Central Valley the direction of flow of the majority of the principal water-courses of Yorkshire east of the Pennine Range is to the east or south-east in accordance with the general slope of the ground and with the dip of the Carboniferous and Cretaceous beds.

The explanation of these features and of the whole topography is to be found in the geological history and structure of the region.

CHAPTER II.

THE GEOLOGICAL STRUCTURE OF EAST YORKSHIRE.

(1) The Solid Geology.

In the foregoing general sketch of the characters of the region the distribution of the principal geological formations has been given, and, as there mentioned, the oldest rocks belong to the Upper Palæozoic and are found in the western portion of the area. They consist of the Carboniferous Limestone and Yoredale Beds, overlaid by the Millstone Grit which usually caps the higher ground and the lofty ridges between the dales. The Carboniferous Limestone occupies most of the surface north-west of a line drawn diagonally from Richmond to Skipton, but south-east of this the Millstone Grit covers a large expanse of country owing to the general south-easterly dip and to folds in the beds. In the extreme north of the area concerned the southern end of the great Durham Coalfield comes in with some small basins of Coal Measures, but these are of no importance for the present enquiry.

The Magnesian Limestone which rests unconformably on the Carboniferous rocks runs from north to south as a narrow band averaging about 5 miles in width and cuts obliquely across the strike of the older rocks. It dips to the E.S.E. and forms a more or less prominent escarpment 300 feet high as far north as Thornton Watlass on the Ure near Masham, north of which only scattered patches of it are seen to the Tees.

The Trias which lies beneath the wide Central Valley consists of the red sandstones of the Bunter with the marls of the Keuper above, but it is rarely exposed to view owing to the thick deposit of Drift occurring along its outcrop. Together

with the Magnesian Limestone it forms a broad and slightly curved belt separating the Carboniferous from the Jurassic-Cretaceous area. Its dip is also in an easterly direction.

The Jurassic beds demand especial attention, as their mode of development has had a profound influence on the water-courses of the region. They constitute an isolated mass of high ground more or less completely cut off from the surrounding country by the Central Valley on the west, and by the Cretaceous escarpment on the south, and are washed on the east and north by the waters of the North Sea. Owing to the presence of an important anticlinal and a synclinal fold, running east and west and dipping to the east the whole configuration of the country has been modified; and we do not find the regular north-east and south-west Jurassic escarpments as in the south of England, but a series of hill-ranges and escarpments trending east and west on the sides of the anticlinal, and a long trough-shaped valley in the parallel synclinal.

The relation of the scenery and drainage to the geological structure and to the characters of the beds is exceedingly well exemplified, as many writers have remarked, but it has not been left unnoticed that there are several difficult problems with regard to the course of certain rivers.

The beds represented in the Jurassic area range from the Lower Lias to the Kimeridge Clay inclusive (4). Locally they vary much in character and thickness, but only the more important variations need here be noticed.

It is remarkable that the beds of most importance from a topographical point of view are frequently of comparatively small value palæontologically.

Beginning at the base of the series there is the Lias which consists of the three divisions, Lower, Middle and Upper. The Lower division is composed principally of soft shales and is about 750 feet in thickness (5); its chief outcrop is along the north-west border of the Jurassic tract where it forms the low ground sloping to the Tees. The Middle division consists of harder shales and sandstones below (the Sandstone Series), and an Ironstone Series above, amounting in all to about 450 ft. It usually makes a marked feature on the surface between the

softer beds above and below. The Upper Lias is a thick argillaceous shaly series, varying from 200 ft. in thickness on the coast to 50 ft. or less in the southern Cleveland Hills.

The Lias is well displayed in the sides and floor of the deep-cut dales which run north and south across the moorlands, as well as at the foot of the western escarpment overlooking the Vale of York, and at various places along the coast (e.g. Robin Hood's Bay).

The Lower Oolites consist mainly of a series of sandy estuarine beds of great thickness with a few thin coals, shales and marine bands. The variation in the thickness and characters of these strata is very considerable; but on the whole the sandy beds are thickest in the north and east, thinning out especially towards the south; but the reverse is the case with the marine bands, some of them developing into important beds of limestone in the Howardian Hills.

In the sea-cliffs the Lower Oolites, excluding the Cornbrash, reach a thickness of nearly 700 feet, and they stretch inland across the northern half of the district forming the Moorland Range of Phillips (2) on the south side of the Esk. Westward they have only about one-third of the thickness which they possess on the coast, and in the Howardian Hills they are represented mainly by limestones of a still smaller thickness and of little topographic influence (6). It is in the Moorland Range that the Estuarine beds possess their typical development, forming a high barren tract of country ranging from a height of 900 feet in the east to nearly 1500 feet at Burton Head in the west and thus constituting the highest ground in East Yorkshire as well as the main watershed of the Jurassic area and the divide between the basins of the Esk and Derwent.

Amongst subsidiary beds of the Estuarine Series the Moor Grit should be mentioned, for it is a tough bed of coarse sandstone which always forms a prominent bank or terrace on the hill-sides.

The Cornbrash, so far as surface features are concerned, is of little importance; it varies from 2 to 15 feet in thickness, and is principally exposed in Newtondale, while in the Howardian Hills it seems to be absent.

The Middle Oolites consist of a large series of argillaceous, arenaceous and calcareous beds. The limestones occur chiefly towards the top of the series, while the arenaceous deposits which prevail in the north thin southwards and are more or less replaced by argillaceous beds. The ranges of hills surrounding the Vale of Pickering on the north and west are composed of Middle Oolitic rocks; on the north are the Tabular Hills with their flat tops formed of Corallian limestones and their steep escarpment facing northward, at the foot of which an intervening low-lying belt of Oxford Clay and Kellaways Rock separates them from the Moorland Range. These Tabular Hills extend westwards from the coast near Scarborough to the river Rye above Helmsley, and here merge into the Hambleton Hills which are composed of the same beds and rise above the Central Valley. South of Gilling Gap they are continued to Malton as the Howardian Hills.

It is owing to the great difference in resistance to denudation of the Oxford Clay and of the overlying Corallian beds that one of the chief physical features of the district is produced; and it is comparable to that of the Lias and Lower Oolites above described.

Turning now to details of the development of the Middle Oolites, there is at the base the Kellaways Rock which is a sandstone of variable character. It increases in thickness from about 12 ft. in thickness at Newbiggin Wyke on the coast to about 75 ft. at Scarborough and 130 ft. in Newtondale where it attains its maximum thickness. At Black Hambleton, which is its north-western limit, it is from 60 to 70 ft. thick, while in the Howardian Hills it has decreased to 15—30 ft. Throughout the district it gives rise to prominent "nabs" along its outcrop, and generally forms a conspicuous step at the foot of the escarpment of the Tabular Hills.

The Oxford Clay is a grey sandy shale passing up insensibly into the overlying Calcareous Grit. It outcrops on the flanks of the hill-ranges of the Middle Oolites. On the coast at Cayton it is about 120 ft. in thickness, but it has diminished to 30 ft. at Whitestone Cliff in the Hambleton Hills. In the Howardian Hills the beds are less sandy, and

the whole Oxfordian Series cannot be more than 80 ft. in thickness.

The Corallian rocks are divisible into a number of beds of limestone and more or less calcareous grit which need not here be enumerated in detail, as their local development is extremely variable, and their classification a matter of dispute. They cover the flat summits of the Tabular Hills, cap the escarpment of the Hambleton Hills, and constitute the northern slopes of the Howardian Hills.

The Lower Calcareous Grit at the base of the series forms the main mass of the hills encircling the Vale of Pickering and it constitutes the flat table-lands of the Tabular Hills as well as their bold escarpment which attains a height of over 1300 feet at Black Hambleton. It varies in thickness from about 60 ft. on the coast to 130 ft. in Newtondale and 200 ft. in the northern part of the Hambleton Hills, but in the Howardian Hills has decreased to 60 ft. in thickness.

The upper beds of the Corallian cap the Tabular Hills and the Hackness outlier, but the individual beds do not usually make any surface-feature, except the Cement Stone in the Howardian Hills, where it is 30—40 ft. thick and forms a good escarpment. The low Haver Hills west of North Grimston are also composed of it.

The entire thickness of the Corallian rocks increases westwards from nearly 200 ft. near the coast to 370 ft. near Kirkby Moorside, but in the Howardian Hills it decreases to 120 ft. near North Grimston and 30 ft. at Acklam.

Of the Upper Oolites the Kimeridge Clay occupies the faulted synclinal of the Vale of Pickering, extending from Gilling Gap to Filey, and forming a flat or slightly undulating valley. Its outcrop is mostly obscured by drift and alluvium. Its exact thickness is unknown but it is certainly more than 200 ft. (7). Along the middle part of the Vale it is brought down by faults against the Middle Oolites, and at the west end between Gilling and Ampleforth a long tongue about two miles wide is let down between parallel east-and-west faults,—a condition of things which has largely influenced the surface-features in that neighbourhood. It is also faulted down against

the north side of the Howardian Hills. The thin Portlandian or Neocomian Clays which succeed the Kimeridge Clay in Filey Bay require no description here, as they are of no topographical importance. They extend westwards inland at the foot of the Cretaceous escarpment.

The Upper Cretaceous beds which consist of Chalk rest with a great unconformity on the Jurassic beds, transgressively overlapping their edges, and as a rule unaffected by the movements and dislocations which have folded and faulted the latter (7). The folds of the older Mesozoic rocks have been denuded before the deposition of the Chalk.

The elevated tract of country south of the Vale of Pickering known as the Yorkshire Wolds, consists entirely of the Chalk, and stretches inland with a regular escarpment from the coast in Filey Bay to the neighbourhood of Thorpe Bassett where the escarpment becomes irregularly indented. Thence it runs in a general south-westerly direction across the strike of the Oolites of the Howardian Hills to Acklam, where it turns to the south-south-east and continues in this direction to the river Humber which cuts through it at Ferriby at right angles to its strike.

The general dip of the Upper Cretaceous beds is at low angles (3°—5°) to the south and south-east, and the series consists of the Red Chalk at the base with the White Chalk above.

Folds.

Before proceeding to describe the drift and alluvial deposits it will be convenient to give an account of the folds and dislocations which have affected the solid geology with results of the greatest importance on the course of the rivers.

The movements which tilted the pre-Jurassic rocks need not here be discussed, as on the whole the dip and strike of these older rocks is simple and the minor complications do not affect our subject of enquiry.

With regard to the Jurassic and Cretaceous rocks it is otherwise. The Jurassic beds have been affected by several transverse axes of elevation and depression having a general east-and-west trend, so that the outcrops of the strata do not form a series of regular parallel bands or escarpments with

the characteristic course of the Mesozoic outcrops further south. The presence of these folds and their position and relations are found to be some of the principal causes in determining the character of the present drainage-system of the region.

The chief anticlinal axis (4) runs from Robin Hood's Bay westwards across the higher ground to the moors west of Burton Head, thus traversing the heart of the Moorland Range. North of this axis the strata roll over and dip to the north, while south of it they dip down into the synclinal trough, the end of which is situated at the western extremity of the Vale of Pickering. The axes of these folds themselves dip slightly eastwards. The axis of the synclinal runs along the Vale of Pickering to the sea near Filey, and owing to this fold the beds round the head of the Vale dip inwards, so that in the Howardian Hills they dip to the north-east and near Helmsley to the east, while along the northern border they dip to the south or south-west. The southern limb of the syncline is buried beneath the Cretaceous rocks.

North of the Esk the Jurassic beds preserve in the main the northerly dip due to the main anticlinal axis, but it is at a lower angle than on the south side of that river.

There is, however, a slight anticlinal roll running from Guisborough Moor in a south-easterly direction, partly along the northern side of the Esk valley (3), and north of this is a synclinal traceable from Great Moorsholme in an easterly direction to Whitby, in which occur the newest Jurassic beds (*i.e.* the Kellaways Rock) north of the Esk (8). Another small anticlinal axis runs obliquely in a south-easterly direction from near Egton to the mouth of Mill Beck in Robin Hood's Bay. A minor synclinal axis is also traceable southwards from near Whitby across Fylingdales Moor and through Blea Rigg, leading to the presence there of an outlier of Middle Oolites (9) (10). A small anticlinal axis is found running westwards from Scarborough across Troutsdale and High Dalby Moor to Lockton, and along this line the beds roll over and have a northerly dip till they meet with the equally well-marked and nearly parallel synclinal beginning near Suffield and ranging

westwards by Hackness Hall and across Allerston Low Moor to the neighbourhood of Lockton and Levisham (9).

Several small folds occur in the north-western corner of the Jurassic area near Guisborough, and are divisible into two sets, of which the more important has a trend a little north of west and south of east and the other roughly north and south (8).

In comparison with the main moorland anticlinal axis these folds have but little direct influence on the configuration of the surface, but indirectly through affecting the course of the streams their presence may occasionally be demonstrated, as will be shown later.

The existence of the great moorland anticline and of the Vale of Pickering syncline has been the primary factor in determining most of the characters of the scenery, and has directly influenced many of the lines of drainage. Reference to this fact has been repeatedly made by many writers, but the subject will here be dealt with in detail.

Faults.

In addition to the folds there are many faults of importance, though in the central part of the Jurassic district they are not numerous. In the north-western corner between Guisborough and Osmotherley there are two sets of faults affecting the Jurassic strata; one set has a course from north to south, and the other from east to west (8) (11). Several long faults of the latter set are traceable across the moors between Guisborough and Whitby. One fault belonging to the other set extends from Runswick nearly to the Esk valley. The fault from the mouth of the Esk at Whitby is also traceable to the south for 3 or 4 miles, and the Peak fault extends southwards from the Peak cliff nearly to Suffield Moor.

A few north and south faults of little importance are noticeable along the north side of the Vale of Pickering, and the most easterly ones of this set are seen at Scarborough, White Nab and Cayton Bay. The Cayton Bay fault is continued into the Cretaceous rocks past Hunmanby, and as it shifts the Chalk as well as the underlying beds its post-Cretaceous date of origin is fixed.

There are extensive east and west faults along the north side of the Vale of Pickering, one of which stretches for 9—10 miles from Brompton to Pickering, bringing down the Kimeridge Clay against the Middle Oolites. Another runs in the same general direction north of Helmsley for about 4 miles.

There is also an important parallel one about 9 miles long which runs past Stonegrave and Ampleforth along the north side of the Gilling Gap; and a similar one on the south side of this Gap extends all the way to Malton and may even affect the Chalk near Thorpe Bassett (4) (13) (14). A parallel one runs south of Gilling Park. These faults have apparently had much to do in determining the existence and position of the Gap, as they have let down a tongue of soft Kimeridge Clay between the harder and more resistant beds of the Middle and Lower Oolites. The same may be said of the faults along the north side of the Vale of Pickering.

An intricate network of faults traverses the whole of the Howardian Hills between Gilling Gap and the Chalk escarpment. The main faults run rather south of east to north of west, and are crossed by minor ones trending rather north of east to south of west. It is very doubtful if any of them affect the Cretaceous rocks, and the probability is that they do not (13) (14).

With the exception of those near Gilling and along the Vale of Pickering, there is rarely any surface-indication of the faults. In a few cases there appears to be some connection between them and the relief of the country, for example, Eston Hill near Guisborough and the long inlier of Borrowby. The water-courses appear to be generally independent of them, though the position of the present mouth of the Esk at Whitby may bear some relation to the fault existing there.

(2) THE SUPERFICIAL DEPOSITS.

We may now turn from the consideration of the solid geology of the region to the Drift, alluvial and other deposits. Of most importance are those of glacial origin.

Glacial Drift. The Boulder Clays, sands and gravels which are attributed to the action of ice are extensively spread over

the plain of York or Central Valley and over the lower hills on each side. Glacial deposits are also found in the Vale of Pickering, but do not as a rule occur in any of the dales opening into it, except in some at the eastern end. But on the north side of the Moorland Range, in the valley of the Esk and in most of the dales which hold the streams draining the northern flanks of this range, there is a considerable quantity of Drift. The country also between the Esk valley and the coast to the north is largely overspread by Drift. A peculiar feature is the number of Drift-filled channels with their floor frequently several scores of feet below the present river-bed (3) (18) (see *postea*).

At various places along the coast from the mouth of the Tees, past Whitby, Scarborough and Filey to Flamborough Head, Boulder Clay occurs with sands and gravels. Further to the south along the chalk cliffs to Holderness are found also various important deposits of Glacial age, but inland they are rare on the surface of the Wolds. Probably the fossiliferous beds banked against the old sea-cliff at Bridlington are pre-glacial (16), and in the Wold valley interglacial marine gravels are found beneath the purple Boulder Clay just below the 100 ft. level.

The central portion of the Jurassic area comprising all the high ground of the Moorland and Tabular Ranges shows no trace of Boulder Clay, and this elevated tract is considered to have formed a sort of 'nunatak' round which the ice swept, but over which it did not pass (10) (17) (18) (3). Very little Boulder Clay also occurs on the Howardian Hills and Cretaceous escarpment.

Such is a sketch of the general distribution of the Drift, but in order to obtain data for determining the pre-glacial or post-glacial age of some of the surface-features more details are necessary, and will therefore be given.

In the Plain of York the glacial deposits never rise much above the 600 ft. contour line, and only attain this elevation along the northern escarpment of the Oolites; towards the south they are not usually more than 400 ft. above sea-level, except at Oulston where the gravels rise nearly to the 500 ft. contour

line. The Lower Boulder Clay reaches a much greater height than the Upper, which is said never to rise above 400 ft. The gravels form a distinct fringe to the great escarpment and run a long way up the dales opening off it (11).

On the banks of the Tees near Eryholme the Glacial deposits reach a thickness of about 100 ft., nine-tenths of which belong to the Upper Boulder Clay. Further south the thickness varies considerably.

The Glacial deposits are mostly at their thickest along the old river-channels which they have filled up. The bottom of the old Tees valley is found by borings to be 90 ft. below high water-mark (8), and the Ouse in the York district has been similarly shown to be 60 to 70 ft. above the level of its pre-glacial bed (19). The pre-glacial valley of the Humber has also been proved to be filled with Drift to a depth of over 100 ft. (15). These old Drift-filled valleys throw an important light on the level at which the land stood in pre-glacial times, and therefore concern most closely the history of the rivers.

With regard to the Drift in the Plain of York mention must be made of the peculiar ridges of Glacial material near York. These are crescent-shaped and almost parallel, and stretch right across the flat-land from Upper Helmsley to York, and from High Catton to Escrick, with an average height of 50 feet and a width of about half a mile. They are intersected by the present rivers and are considered by some geologists to be the terminal moraines of the glacier which occupied the Vale of York (14) (18). There is another Esker-like ridge about 3 or 4 miles west of Ripon.

Attention may now be directed to the Esk valley and its tributary dales. Boulder Clay extends along the main valley from its mouth as far west as Castleton, and up the valley of the Murk Esk as far as Hazel Head, as well as up Glaisdale, Fryup Dale, and over the lower moors on both sides of the Esk. But Danbydale, Westerdale, and Basedale are quite free from Drift (10). The Ingleby escarpment appears to have offered an insuperable barrier to the passage of Drift from the west. The good state of preservation of the escarpments on the moors

above 800 ft. has also been considered as a proof that they have never been glaciated (18).

On the west side of the Ingleby escarpment at Kildale we find a great mass of gravel and Boulder Clay, and at Midnight Wood the gravel reaches to a height of 700 ft. up the face of the escarpment.

The floor of the pre-glacial valley of the Esk is found by borings to have been 50 ft. below the present one, and the valley was also wider. (See *postea.*)

North of the Esk valley the Glacial deposits are widely spread over the lower ground and along the coast, but disappear entirely above 850 ft. (8), becoming thin at 600 ft., and it is only the Lower Boulder Clay which attains the high levels. Thus Moorsholme High Moor near Guisborough, and Danby Low Moor, which rise above this level have escaped glaciation. The so-called Middle Glacial Sands and Gravels reach up to heights of from 400 to 600 ft. above sea-level along the escarpment, but the Upper Boulder Clay probably does not rise above 400 ft.

Numerous old pre-glacial valleys filled more or less with Drift occur in the Cleveland part of the district, and the floor of the old valleys is found to be from 70 to 100 ft. below the beds of the present streams (3) (8).

Turning now to the Vale of Pickering we find that it contains several patches of Boulder Clay though some geologists have doubted the presence of any true Boulder Clay in this part (3) (17) (18). At its east end the Drift from the Vale of York enters the Gilling Gap as far as Ampleforth and forms there some prominent hills. Other patches occur along the north side near Helmsley, Sinnington, Pickering, Thornton Dale and Seamer, but at none of these places is it more than a few feet in thickness (12). In some cases it overlies a considerable thickness of gravel. At the mouth of the Vale near Filey the Boulder Clay is at least 150 ft. in thickness and forms the whole cliff. A few isolated patches have been mapped in the middle of the Vale towards its eastern end (*e.g.* near Kirkby Misperton) but none along its southern side.

The fringe of Glacial Drift along the coast extends almost

without interruption from Saltburn to Flamborough with an average width of two miles, capping the cliffs, and possessing a very variable thickness. At Runswick it fills up part of the valley; on the west side of Whitby it descends to sea-level; the central part of Robin Hood's Bay is occupied by a thick mass of Glacial deposits, and the high ground around the Peak (Ravenscar) shows signs of having been covered with Drift even up to a height of 850 ft. (9). South of this point the area over which the Drift is spread widens, and in the two Drift-filled valleys leading down to Hayburn Wyke its thickness must exceed 100 ft. Nearer Scarborough the Drift mainly consists of gravel, and stretches inland up the valley at the foot of the Hackness Hills towards Harwood-dale as far as Keasbeck Hill, while near Scalby it covers a large area and wholly composes the sea-cliffs between Long Nab and Scarborough Castle. The cliffs above the South Sands of Scarborough are also formed of Boulder Clay, and a well-boring at the Grand Hotel proved this deposit to be 200 ft. thick and to fill up an old valley with its floor nearly 100 ft. below the present sea-level.

Towards Filey the capping of Boulder Clay on the high cliffs varies from 25 to 75 ft. in thickness, and almost the whole semicircle of cliffs surrounding Filey Bay is composed of Boulder Clay down to and below sea-level.

Nearer Flamborough the Chalk cliffs are similarly capped, and in Bridlington Bay the Boulder Clay rests on the top of an old sea-cliff 30 ft. high which extends all along the eastern edge of the Wolds a little below the 100 ft. contour line and may be of pre-glacial age (16). The interesting series of Glacial gravels at Bridlington need not here be described.

The Boulder Clay also extends into the Wold valleys, and marine gravels occur beneath it just below the 100 ft. level, but in the lowlands of Holderness they are not more than 50 ft. above the sea.

Post-glacial deposits. Post-glacial deposits in the form of gravels, sands, clays, silt and peat occur in various parts of the district, and are also of considerable importance for our present enquiry.

Those in the Vale of Pickering are of special interest.

Along its northern side there are two or possibly three terraces of finely stratified gravel, composed of sand and waterworn pebbles of the neighbouring Oolite rocks with many shell-fragments. The highest terrace is well marked about Wykeham, Hutton Bushel, and Ayton, at a height of 225 ft. above the sea; a second lower one is indicated at about 140 ft., but the traces of the third and lowest are not so distinct and become mingled with the sand and gravel of the rest of the valley (12). It is thought by some geologists that these are the remains of old raised beaches when an arm of the sea occupied the Vale of Pickering, for they lie at some little distance above the watershed at Filey, and seem to mark successive stages in the elevation of the land.

On the south side of the Vale no such distinct terraces have been recognised, but west of Flotmanby there is a thick covering of sand containing angular or partially rounded fragments of chalk and flints, and extending along the foot of the escarpment with a thickness of 30—40 ft. It is doubtful if the view is correct which would correlate this deposit with the gravels on the north side.

The clays and alluvium which are spread over the general surface of the Vale of Pickering reach a thickness in places of over 100 ft. but average 60—70 ft. The deeper layers may be of Glacial or pre-glacial age. The thickest portion in the western part of the Vale seems to fill a channel following a line at first roughly parallel to the Rye but then turning off to Kirkby Misperton, and thence eastwards past Scrampston Hall and Knapton, where it bends north-eastwards to Yedingham and thence turns again more to the east past Foulbridge and Sherburn. Along this line the deposits average about 100 ft. in thickness, and probably mark an old river-channel the floor of which lies some 30 or 40 ft. below the present sea-level.

Recent alluvium occurs along the banks of the present rivers and merges into the older alluvium of the Vale, but along the Derwent between Ayton and Sherburn this recent alluvium rises to a higher level than the surrounding country, owing to the river overflowing its banks during flood (12).

Some of the old dry valleys on the northern slopes of the Vale are marked by accumulations of local gravel and sand, as is usual in a district with large outcrops of porous strata.

In the large inlet from the Vale between Norton and Settrington, which is overspread with post-glacial deposits, there is a great terrace covered with gravel overlying the clay of the valley; and it extends from Malton to Crambe. But this is apparently of later date than the thick deposit of false-bedded gravel in the old valley running north and south through Malton (13).

There are also large spreads of late gravel near Pickering, and along the valley between Slingsby and Gilling.

In the Vale of York much alluvium is found, some in relation to the present rivers and some in isolated patches or strips In the middle portion of the Vale the whole of the comparatively flat ground between the city of York and the range of hills to the north-east by Stillington and Sheriff Hutton is covered with clays and sands, 20—30 ft. in thickness, and forming the so-called 'older alluvium.' One large isolated patch of lacustrine clay north of Sheriff Hutton is known as Terrington Carr, and marks the site of a lake even in historic times.

North of York the area covered with warp and 'lacustrine' clay and sands reaches up to the neighbourhood of Thirsk, while southwards it extends to the valley of the Humber, where these deposits have a thickness of from 25 to 90 ft., thinning away against the rising ground (20).

There are river terraces (similar to those in connection with the Derwent near Malton) along the Swale west of Northallerton, the Ure north of Ripon and its tributary the Laver. In the case of the Ure there are three, the highest being from 25—50 ft. above the present river (11).

In the Wold district gravels are always found along the winding dry valleys, and they are entirely composed of chalk fragments and flints, except towards the east where foreign pebbles from the Drift are intermixed. The amount of gravel varies according to the size of the valley and the area of drainage. There is a good development of these deposits in

the main Wold valley from Weaverthorpe to North Burton. At Foxholes they reach a thickness of 40 ft. (20).

The only example of a raised beach on the coast is at Saltburn, where at a level of 30 ft. above the sea such a deposit occurs, containing none of the shells which are now most common on the coast (8). No other traces of raised beaches have been recognised in the neighbourhood, but this is probably due to the rapid denudation continually taking place along the coast.

CHAPTER III.

THE PHYSICAL HISTORY OF EAST YORKSHIRE.

It is necessary to examine carefully the sequence of events in the physical history of the region and the conditions which have prevailed at different stages in the process of its development in order to be able to trace the evolution of the present system of drainage. The foregoing description of its geological characters and structure has furnished us with the requisite data for such an examination.

Commencing with the oldest beds of the region it is needless to discuss the conditions under which the Carboniferous rocks were deposited, since they practically form the platform on which all the later deposits have been laid down.

At the close, however, of Carboniferous times, great changes took place in the physical geography, and over the region here concerned earth-movements of considerable magnitude occurred, accompanied by denudation. Upon these disturbed and eroded rocks the Permian Magnesian Limestone was unconformably deposited, and though its outcrop in East Yorkshire is now limited to a narrow band there is no doubt that it originally extended far to the west over the central portion of the county. It is probable that the break between the Carboniferous and Permian points to a period of elevation when the greater part of England became dry land. But we have at any rate no knowledge or means of tracing any of the pre-Permian lines of drainage which may then have been developed.

There is next a break, marked likewise by an unconformity,

between the Permian and the Trias. The Triassic rocks by their lithological characters indicate conditions somewhat resembling those in Permian times—*i.e.* the conditions of shallow or enclosed seas, or salt lakes.

In Rhætic and Liassic times a more complete submergence set in, the whole area sinking beneath the sea, which gradually enlarged its boundaries. There was apparently no marked interruption in the sedimentation when once the subsidence began to set in at the end of the Triassic period, for there is a complete passage from the Trias to the Rhætic, and from the Rhætic to the Lias.

It was towards the northern extremity of the Anglo-Parisian basin that the Jurassic rocks of Yorkshire were deposited. This basin was bounded on the south by the Auvergne plateau, on the east by the Vosges Mountains and on the west by the Palæozoic rocks of Brittany, while northwards it extended to the north of Yorkshire and up the western side of Scotland (4) (21). "It is probable that the land, from which the material was derived, of which they [the Jurassic rocks] are composed, lay away to the north-west, perhaps occupying the position of the present Pennine Chain and the Palæozoic tract to the west of it. Littoral conditions or at any rate shallower water prevailed in Middle Lias times...and there are signs that a tongue of land separating the Liassic sea of North Yorkshire from that of South Yorkshire existed at this period" (4).

In Upper Liassic times submergence set in again, and the sea deepened and extended considerably, though the neighbourhood of land is indicated by the organic remains. No part of the Lias was in fact formed in very deep water or far from land, but the sea appears to have been open to the east.

At the commencement of the Oolitic period the whole area was subject to irregular movements. Part was elevated into dry land resulting in the local denudation of the pre-existing beds, as in Bilsdale; part was covered with fairly deep water, and part oscillated between dry land and shallow water with estuarine conditions. In fact during the Lower Oolitic period changes from one condition to another frequently took place over the whole district, and thus led to the accumulation of a

variable series of estuarine, marine, and freshwater strata. The greater thickness of the coarse sandy estuarine beds towards the present western escarpment indicates that the land still lay to the north-west, though at what distance can only be a matter of conjecture. "During this period the north-east of Yorkshire formed part either of the estuary of some large river, or possibly of a series of channels or straits between the neighbouring islands" (4). To the south more open water prevailed, and purer limestones were generally formed.

The deposition of the Cornbrash was ushered in by a subsidence, so that the sea spread over the north-east side of the area, but apparently did not extend over the western and northern portions till Oxfordian times. The Kellaways Rock by its rapid and uniform attenuation to the south and south-west indicates that at this time also the source of supply still lay to the north.

The subsidence, however, increased and extended further during the deposition of the Oxford Clay, but the water was now deepest towards the south-east.

In Upper Oxfordian times there was a silting up, but in Corallian times it finally cleared and became free from mud, though probably not simultaneously nor uniformly over the whole area. Different basins of accumulation may also have existed.

At the close of the Middle Oolitic period a great and wide-spread depression took place. It is possible that the sandstones and limestones of the Middle Oolites, south of Malton, suffered some erosion at this time before the deposition of the Kimeridge Clay, but there seems to be no adequate reason for thinking that the Vale of Pickering formed a great gulf between sea-cliffs of Middle Oolite, and that in this enclosed gulf the Kimeridge Clay was laid down (6). The boundary lines are not those of a coast-line, but are faults traceable into the older formations; while in many parts the Kimeridge Clay conformably succeeds the Corallian Rocks. The Vale of Pickering did not in fact originate till considerably later.

Judging from the thickness, uniformity of character and absence of littoral deposits the Kimeridge Clay must have

originally extended over a very large area, though we have not sufficient data to determine its precise limits. Nevertheless, as in the case of the earlier Oolitic beds, we may safely conclude that it spread far to the west and north of its present boundaries, and reached out over the present outcrop of the Triassic rocks and much of the Palæozoic area.

The present limited extent of the Jurassic rocks is universally recognised to be the result of denudation subsequent to deposition.

During the Portlandian period fine argillaceous sediment continued to be accumulated under very similar physical conditions, though an east-and-west barrier, situated apparently a little south of the present northern escarpment of the Wolds, cut off the northern from the southern sea (4).

The commencement of Cretaceous times was ushered in, after a slight interval, by the deposition in the same sea of the Neocomian clays with almost identical lithological characters.

We have now come to a critical period at which earth-movements of great importance took place. It is indeed held by some geologists that the above-mentioned barrier, which first shows its presence in Portlandian times, was formed at the close of the Oolitic period by an elevation along an east-and-west line parallel to the Howardian Hills (4). It is further considered that at the same time movements of a marked and violent character threw all the Jurassic rocks into a series of folds trending east and west, and caused the dislocations parallel to them (4). The principal anticline of the Moors and the syncline of the Vale of Pickering were at this period initiated or completely formed; and thus the structure which has had such a profound effect on the drainage system was produced at this date.

At the opening of the Upper Cretaceous period another series of movements of less intensity set in; and probably the faults ranging north and south were then formed, together with the general westerly elevation and tilting eastwards of the Jurassic rocks. This elevation was of such a nature and extent as to bring them all well within the reach of denuding agencies, though whether marine or subaerial forces played the

most part in the process of denudation it is impossible to say.

There is, however, the clearest evidence that before the deposition of the Chalk all the older rocks were subjected to great erosion, so that when the area was again depressed the Upper Cretaceous deposits spread over the worn edges of the older folded and faulted beds with a marked unconformity, overlapping even the Lower Cretaceous (14) (32).

From the thickness of the Chalk along its present escarpment, the absence of any signs of littoral conditions, and the dip of the beds, we may conclude that it formerly extended entirely over the present Jurassic area. The highest parts of the submerged Oolitic surface may, however, only have been covered by the uppermost beds of the Chalk, which may therefore have been thin over the ridge of the main anticline.

How far to the north and west the Upper Cretaceous sea extended when at its maximum development there is no means at present of precisely determining, but it appears to be generally acknowledged that it stretched out westwards on to the present Palæozoic area, and perhaps even touched the Pennine Chain. Jukes Browne (21) says :—"It is clear that the Upper Cretaceous sea, aided by subsidence, marched across the Jurassic ground and formed a plane of erosion that sloped gradually up to the Palæozoic Hills. Now at Garraby, which is nearly the most westerly point of the Yorkshire Wolds, the Red Chalk or homotaxial equivalent of the Gault rests directly on the Lias at an elevation of about 600 ft.; a few miles further west it must have lain on the Trias, and thence the sea-floor probably passed with a gentle slope to the foot of the Pennine Hills. How far the Red Chalk extended in a westerly direction we cannot say, but sooner or later it probably passed into a more littoral deposit; comparatively deep water (100 to 150 fathoms) may however have continued to within a short distance of the shore-line, and the Pennine Hills probably rose up from the sea with a steep slope, as the Riviera does from the Gulf of Geneva. Thus, if the base of the Chalk reached to what would now be a level of 900 ft. over the edge of the Triassic boundary, and we suppose the water there to have

been 600 ft. deep, it would not have over-topped the Pennine Hills which even now rise in many places to heights of over 2000 ft., and in the Cretaceous period the watershed must have been much higher than it is now."

But in the Middle and Upper Chalk times the same author (21) thinks that the crests of the Pennine Range were submerged, for a far greater subsidence set in and continued till the close of the Cretaceous period, though the western portion of the British Isles did not sink so deeply as the eastern. The actual amount and extent of the subsidence are difficult or impossible to estimate, but the White Chalk was probably formed in water of not less than 400—500 fathoms deep.

From the above considerations there seems to be justification for holding that the whole of the region now constituting Eastern Yorkshire was overspread by the Upper Chalk.

After this great submergence the gradual upheaval of the whole British area commenced, and the sea-floor was elevated into land, the British Isles becoming part of a continent which stretched far westward and southward. Great sheets of Chalk must then have formed the surface of the ground, and owing to the elevation being greater in the west the surface sloped down towards the east or south-east, as Davis (1) has pointed out. Assuming that the upward movement was regular and unaccompanied by folding, the slope of the ground would in the first instance correspond with the dip of the beds. As the land-surface gradually rose above the sea the action of the waves must have been instrumental in producing a generally plane or slightly sloping surface, but to what extent marine agencies eroded the Chalk as it came under their influence is doubtful.

There does not appear to have been any folding of the beds at this time, but there was some faulting (*e.g.* near Speeton) during the uplift, though perhaps marine erosion more or less obliterated its effects on the surface before the latter became dry land. (The southerly dip of the Chalk on the south side of the Vale of Pickering is considered to have been caused by a later movement in Miocene or late Oligocene times when the Cretaceous and Lower Tertiary beds of the southern

counties were thrown into folds trending generally east and west.)

It was upon the land-surface formed by this post-Cretaceous uplift that a system of drainage was first established in the region with which we are dealing, and, according to Davis' theory (1), those water-courses were marked out which are the direct ancestors of the rivers now existing.

At no subsequent date is there evidence that the sea overspread and denuded the whole region, though minor depressions caused slight incursions.

We have, therefore, to regard the present surface-features as the results of a long course of subaerial denudation continued without cessation, though not always at the same rate or with the same intensity, since the first post-Cretaceous elevation.

On the original land-surface constructed by this movement there were established the primary "consequent" rivers depending for their direction and course on the initial slope of the ground. As Davis (1) has pointed out, this slope was to the east or south-east; and accordingly it was in this direction that the rivers ran down to the sea, as will be described later on.

Towards the close of Oligocene time when the area had been nearly reduced to base-level and an extensive "peneplain" of diverse stratal composition thus formed, there was a further general upheaval of the British Isles and of the whole of western Europe. By this movement the rivers which had attained old age were revived. Thus a second cycle of river-development was started.

At this time there appears to have been the slight folding of the Cretaceous, as previously mentioned, and it occurred along the line of the moorland anticlinal which had been formed in pre-Cretaceous times. This movement not only gave the Chalk its southerly dip on the south side of the Vale of Pickering, but ridged up the surface of the peneplain along the centre of the Jurassic tract with important effects on the drainage, as will be shown subsequently. The occurrence of movements along old lines of folding has been shown by Godwin Austin and more recently by Bertrand to be a common phenomenon.

The general elevatory movement of which this was a part is usually known as the "Miocene upheaval," and during the whole of this period and much of the succeeding one the revived rivers were busy sculpturing the surface of the land and producing the main features of the present topography.

A third cycle was initiated by a period of subsidence which began probably towards the end of the Pliocene period and lasted till its close. This movement checked the development of the river-system, and drowned the lower reaches of the streams, but did not result in any considerable incursion of the sea. The extent of the downward movement is indicated perhaps by the old sea-cliff near Bridlington, if it is really of pre-glacial age and buried under Boulder Clay. It is found along the 100 ft. contour in that district and marks an old sea-margin (16).

The North Sea is held to have been formed at this date by a local subsidence, and the general outline of the coast marked out (15), though subsequent marine denudation has caused a great loss of land and recession of the cliffs.

As previously described there are many old river-channels in this region which are more or less completely filled with Boulder Clay, etc., and the floors of which near the present coast-line are from 50 to 100 ft. below the sea-level. The depression of these is generally held to have taken place at this period, so that if we maintain that the Glacial deposits which fill them were formed by land-ice there must have been a considerable upward movement of the land before the Glacial Period commenced.

Upon the views adopted of the nature and origin of the Boulder Clay will depend the description of the conditions of the Ice Age. If we hold that the deposits of this period are of marine origin, it follows that a depression of many hundred feet must have taken place at the commencement of this period, drowning the whole country over which the Boulder Clay is spread to a depth corresponding at least to the level at which it is found. If on the other hand it is regarded that the Boulder Clay is a product of land-ice it is probable that an elevation of the land occurred (18). Whichever theory is

adopted it is evident that in either case, whether by sea or ice, the river-system had its development stopped; the old valleys were more or less filled with new materials, and a sheet of Drift irregularly distributed over the greater part of the region.

On the departure of the glacial conditions there was a general revival of the pre-existing rivers, though the new accumulations of material on the surface of the land brought about modifications of considerable importance.

It is necessary, however, to look somewhat more closely into the conditions of the Glacial Period and its effects on the region in question. The land-ice theory appears to offer fewer difficulties than any other, and to explain matters more satisfactorily. Moreover it has the support of most of the geologists who have devoted special attention to this area (10) (15) (18). We may accordingly examine its application, for the course of the glaciers has an intimate connection with the modifications in the stream-courses by the Drift (18) (3).

The land as a whole must have stood at a much higher level than it does now, and the great glacier which flowed eastwards over the centre of England sent off one lobe which descended the Vale of York, leaving its crescentic terminal moraines near York itself and spreading a sheet of Boulder Clay over the lower ground. It impinged upon but did not cross the Jurassic escarpment till it came to Gilling Gap, through which a small tongue seems to have penetrated into the Vale of Pickering. The main mass of the great glacier from the west swept down Teesdale and southwards along the coast, spreading a sheet of Drift all the way and covering the lower ground north of the Esk Valley, and even entering that valley and extending far up some of its tributary dales (18).

No ice, however, seems to have crossed the centre of the Jurassic area, nor the Wolds.

An interglacial submergence to 100 ft. below the present level is believed to have occurred; and the marine gravels of Holderness were formed by it (15), the Vale of Pickering being invaded at the same time and receiving a covering of marine deposits. But this depression appears only to have been temporary, and the glaciers returned again.

After the land had finally lost its icy mantle at the close of the Glacial Period, the streams would be formed afresh on its surface; the old ones would be revived and seek again to excavate their channels, while the drift-deposits would introduce considerable modifications in their course. Some of the pre-existing valleys had been completely filled up, and the streams were therefore turned aside into new courses or even dammed back so as to form lakes.

This first post-glacial stage corresponds to what may be termed the fourth cycle in the development of the rivers.

Towards the close of this cycle there was a depression along the sea-coast to the extent of about 30 ft. below the present level, as shown by the level of the raised beach at Saltburn, which is undoubtedly post-glacial (8). The effects, however, of this movement are not directly visible inland, though the gravels up the dry Chalk valleys of the Wolds may be referable to this stage (15).

An upward movement then set in, raising the land, at any rate in Holderness (15), to a level of 50 feet above that at which it now stands; and the "buried forests" of the Humber then flourished. A fifth cycle was thus defined.

A period of irregular and discontinuous subsidence then occurred, interrupted by stages when the land remained stationary. The former forests were buried at this time. There is not much evidence at present collected to show how far or to what extent these movements spread northwards and inland from the Humber, or whether they were purely local and confined to a narrow tract near the coast.

The result of these subsidences brought the surface of the land to its present level, and marked the beginning of the last and sixth cycle in which we may consider ourselves to be at the present day.

The signs of this varied history of East Yorkshire are impressed on the surface of the country, and exhibited in the characters and relations of the existing water-courses.

CHAPTER IV.

THE PRESENT RIVERS AND THEIR RELATIONS TO THE GEOLOGICAL STRUCTURE.

Before we attempt to discover how the present rivers have obtained their existing relations to the geological structure and to find out the reasons for their dependence upon it or their disregard for it, we must trace out their courses in some detail and observe their immediate relations to the rocks which they traverse.

For convenience of treatment the rivers may be divided into two geographical groups: (1) the rivers draining the Palæozoic area and the Plain of York; and (2) the rivers draining the Jurassic and Cretaceous areas.

The first group may be subdivided into (i) the Tees and its tributaries, and (ii) the Ouse and its tributaries from the western highlands and from the escarpments on the east (with the exception of the upper portion of the Derwent above Crambe).

The second group comprises (i) the Esk and its tributaries, and the smaller streams to the north of it; (ii) the Derwent and its tributaries; and (iii) small coastal streams.

Group 1. All the rivers in this group have the common characteristic of flowing down the general slope of the Palæozoic surface for a great part of their length from their source, but to a large extent are independent of its changes in geological structure. They also have in common the feature of breaking through the Magnesian Limestone escarpment more

or less at right angles to its strike, and then turning suddenly to the north or south along the central Triassic valley. This sudden change in their direction of flow from east or south-east to north or south is most noticeable.

The Tees, Swale, Ure, Nidd, Wharfe and Aire are those which behave in this manner; and the first mentioned is the only one which turns to the north in the Central Valley.

(i) The Tees.

The line of watershed between the basins of the Ouse and the Tees runs along the northern escarpment of the Oolites to Swainby, whence it trends almost due west across the comparatively low Drift-covered Triassic plain north of the river Wiske past Great Smeaton to North Cowton. This watershed attains its greatest height on the Oolitic escarpment where it reaches up to a little over 1400 feet, but on the Triassic plain near Cowton it sinks to 150 feet above sea-level. All the drainage on the north side of this watershed falls into the Tees which with its tributaries drains an area of 708 square miles, of which Jurassic rocks only occupy 78 (30). This Jurassic portion is entirely drained by its tributary, the Leven, rising from the Kildale Gap in the Oolitic escarpment.

The Tees rises in the Cross Fell district and flows in a general south-easterly direction past Middleton and Barnard Castle to Wycliffe where it bends round to the east-north-east and runs thus to Gainford where it again turns south-east and crosses the Magnesian Limestone outcrop. After a series of gigantic loops and curves between Croft and Yarm in the Triassic plain it takes a north-easterly course along the strike of the beds past Stockton and enters the sea.

The series of patches of alluvium reaching from Wycliffe past Kirby Ravensworth and Gilling to Catterick where the Swale crosses the Magnesian Limestone outcrop suggests that at some recent date the Greta flowed along this line. But we need not concern ourselves here with any of the tributaries of the Tees except the Leven.

The Leven is formed principally by the union of a number of small streams flowing out of the great embayment in the

Oolitic escarpment near Ingleby Greenhow. These flow at first in a general north-westerly direction down the dip of the Lower Lias which lies here on the northern flank of the moorland anticlinal, the axis of which emerges near the head of the embayment. The becks from Kildale and the Guisborough embayment flow in a westerly or south-westerly direction against the dip of the beds, and join the Leven near Stokesley. The Leven thus formed leaves at this spot the Lower Lias and meanders over the Trias in a general north-westerly direction to Yarm where it joins the Tees. On its course it receives several small becks from the face of the Oolitic escarpment which flow northwards or north-westwards. Such are Broughton Beck, West Beck, Faceby Beck and Potto Beck. Along practically the whole course of the Leven the ground over which it runs is thickly spread with Drift, but with regard to the solid geology of its drainage area it is for the most part an anti-dip stream.

(ii) The Ouse and its tributaries.

The Ouse flows down the Central Valley along the strike of the Triassic beds. From the Tees it is only separated at its head by a low watershed. Its general direction is southwards. But with regard to its tributaries it is most noticeable that all those from the western district have a course more or less at right angles to that of the Ouse before they enter the Triassic valley, and that they are conspicuously 'dip-streams' while the Ouse is a 'strike-stream.' The sudden change in the general direction of the water-courses is most striking. In this respect they agree with the Tees.

The most northern member of this western group is the Swale. This river has a general easterly course over the Carboniferous rocks past Muker, Reeth and Richmond to the Magnesian Limestone at Catterick which it crosses, and then bends to the south running along the strike of the Trias down the central plain to join the Ouse at Myton-upon-Swale near Boroughbridge.

The Ure flows similarly due east as a dip-stream past Hawes and Askrigg to Thornton Steward where it trends to the south-

east and crosses the Magnesian Limestone obliquely near Masham. On thus entering the Triassic plain it likewise becomes a strike-stream flowing past Ripon and Boroughbridge to join the Swale at Myton, below which the strike-stream is known as the Ouse.

The other western tributaries, the Nidd, the Wharfe as far down as Weston, and the Aire as far as Castleford, have a strong south-easterly trend across the Carboniferous, but then run almost due east crossing the Magnesian Limestone and joining the Ouse nearly at right angles. The Aire is joined before crossing the Magnesian Limestone by the more easterly flowing Calder, and after receiving the waters of the Ouse in the Triassic plain is known as the Humber, crossing the strike of the Triassic, the Jurassic and Cretaceous beds at right angles.

The Ouse with all its tributaries drains an area of over 1800 square miles, of which nearly one-third consists of Trias, and more than one-half of Carboniferous rocks (30).

The river Ouse itself is formed by the union of the Swale and Ure at Myton in the Triassic plain, and from this place it runs in a general southerly direction with a sinuous course down the Central Valley and along the strike of the beds past York and Selby to the neighbourhood of Howden where it falls into the Aire which crosses its track. At York the Ouse is 41 feet above sea-level and at Selby only 18 feet.

Besides the tributaries from the west which have been briefly described there are several from the north and east. The river Wiske is the most northern tributary of the Ouse, and rises at the foot of the Oolitic escarpment north of Osmotherley; thence it runs north-westward, at right angles to the strike of the Lower Lias, Rhaetic and Trias which it traverses, to West Rounton. From this place it turns more to the west and flows still against the dip of the beds right into the middle of the Triassic plain where near Great Smeaton it curves sharply round to run almost due south along the strike past Danby Wiske, Northallerton, North and South Otterington and Kirkby Wiske, uniting with the Swale near Pickhill. On its way it receives several small anti-dip streams from the

Oolitic escarpment on the east, chief of which may be mentioned Brompton Beck.

The next tributary from the north to be mentioned is Cod Beck, which also has a peculiar course. Arising from the Jurassic escarpment south of Osmotherley as an anti-dip stream it runs at first due west against the strike of the Lower Lias. It is here almost connected with the head waters of the Wiske by a strip of alluvium along a line to the north. But near Foxton, Cod Beck turns to the south and runs along the foot of the faulted Jurassic outlier of Borrowby and parallel to the fault and to the strike of the beds, past Thirsk to the neighbourhood of Dalton where it is joined by an anti-dip stream flowing westwards from the Oolitic escarpment and known along different parts of its course as Willow Beck, Isle Beck and Thirkleby Beck. Here the Wiske itself turns abruptly westward and joins the Swale in the Triassic plain at Topcliffe. Several small becks flow down from the escarpment to join the Wiske in its southerly course from Foxton to Thirsk, but these call for no special mention.

Another strike-stream, nearly parallel to this part of the Wiske, and bearing various names along its course, flows southwards from Boltby under Whitestone Cliff obliquely across the Lower Lias, falling into Thirkleby Beck south of Great Thirkleby.

Of tributaries from the east, in addition to those above mentioned, there is Elphin Beck, an anti-dip stream issuing from Gilling Gap near Coxwold and receiving several small affluents from the northern side of the gap. It flows south-westwards past Coxwold and Husthwaite, cutting indifferently across the lines of fault which here occur, and thence it meanders across the Triassic plain to join the Swale at Cundall.

The river Foss arising south of Gilling Gap near the west end of the Howardian Hills and with the Moor Farm Reservoir at its head, runs at first as an anti-dip stream across the strike of the Oolites between Brandsby and Crayke in a general south-easterly direction without any reference to the position of the faults. Thence it flows past Stillington to Far Moor on

the railway from York to Malton as a strike-stream. Here it again turns to the S.S.W. past Strensall across the Triassic plain and against the dip of the beds, over which it meanders to York in a general southerly direction and is known as the River Foss or Foss Navigation Canal. Here it joins the Ouse.

The other strike-streams in the Triassic plain, such as the Derwent and Foulness, will be described later with their tributaries.

Group 2. The rivers draining the Jurassic and Cretaceous districts constitute this group and with the exception of the Leven and the small anti-dip streams above described, they carry off all the drainage of the Jurassic area.

This area falls into four natural divisions, based on physical characteristics, and corresponding with the main geological divisions of the strata.

(*a*) The low ground formed by the Lias along the northern and western margins, much covered with Drift and later deposits. This may be further subdivided into (1) the plain of Cleveland with its surface sloping gently from the foot of the steep Oolitic escarpment to the Tees, and drained by the Leven and smaller streams, already described; (2) the low undulating Liassic tract on the east side of the Vale of York with its drainage into the Ouse system, as above described; (3) the long outcrop south of Gilling Gap under the Howardian Hills forming a low range of hills from Easingwold to the Derwent, and beyond this running out into a series of small promontories between the little streams from the Cretaceous escarpment. All this ground is drained by anti-dip streams, most of which have been mentioned above.

(*b*) The moorland tract. This district, of which we have not as yet described any of the rivers, comprises the high ground composed of the thick Estuarine sandstones and marine beds of the Lower Oolites. This series forms a bold escarpment above the Lias, rising to heights of 800 to over 1400 feet. In the central part of the district these beds form the main watershed of the Jurassic area, corresponding very closely with

the axis of the principal anticlinal, frequently termed the 'Moorland anticlinal.'

The whole district has a general slope to the east, as previously mentioned, the heights along the watershed increasing to the westward from about 900 ft. near the coast to nearly 1500 feet at Burton Head in the west. The river Esk divides it into a northern and a southern portion. The southern portion, constituting the main mass of the moorlands and corresponding to Phillips' Moorland Range, is intersected by numerous deep valleys occupied by streams running down from the watershed and frequently cut deep into the Lias. The drainage of the moorlands is conducted by them partly northwards into the Esk, and partly southwards into the Vale of Pickering, from which it is ultimately carried off by the Derwent. Both sets of streams are essentially dip-streams. The northern portion on the north side of the Esk valley has its surface generally lower and more uniform, having been scoured by the ice, and having had its old valleys filled with Glacial Drift. The streams which drain it flow with few exceptions northwards or north-eastwards direct into the sea.

(*c*) Between the Moorland Range of the southern portion and the Vale of Pickering lie the Tabular Hills composed of the Middle Oolites and rising with a bold escarpment above the slopes of the Moorland Range. At Black Hambleton in the west this escarpment attains a height of 1300 feet, but falls gradually to the east to about 600 ft. The surface of this Middle Oolitic district also slopes down regularly to the Vale of Pickering. It forms a remarkable tableland with conspicuous flat-topped hills, and it is cut through by a continuation of the dales on the south side of the Moorland anticlinal. Numerous shorter streams also traverse its surface and find their way down into the Vale of Pickering. At its western end it curves round forming the elevated plateau of Hambleton, which is cut off on the south by the faulted valley, frequently mentioned as Gilling Gap; but beyond this the Middle Oolites are continued in an easterly direction to Malton as the Howardian Hills which scarcely rise more than 500 ft. above sea-level. At Malton they are cut through by the valley of

the Derwent, and a short distance east of it pass below the escarpment of the Chalk.

(*d*) The Vale of Pickering forms the last subdivision of the Jurassic district. It consists of a long low-lying almost flat area of Kimeridge Clay, and is for the most part less than 100 ft. above sea-level. Though its natural outlet seems to be into Filey Bay on the east or through Gilling Gap on the west, it sends all its drainage through the Howardian Hills by the narrow valley of the Derwent at Malton. At Filey the watershed is 130 ft. above sea-level, and at Gilling Gap about 225 ft., while at Malton the edge of the escarpment through which the river breaks is between 200 and 250 ft. But whereas in the last case the whole height is composed of the solid Oolitic rocks, in Gilling Gap the height is partly and at Filey wholly made up of Boulder Clay. The Vale of Pickering is drained by the Derwent which flows longitudinally from east to west along the synclinal trough but against the dip of its axis; and it receives the numerous streams which flow down from the Middle and Lower Oolitic regions on its north side, but scarcely any from the Chalk escarpment on its south side.

Having thus sketched the main features and subdivisions of the Jurassic region we may now give fuller details of its water-courses and their relations to the geological structure.

Commencing with that portion of the moorland region which lies north of the Esk, we have noted that its drainage is mostly by small streams flowing northwards into the sea. The watershed follows a line across Guisborough Moor, Danby Low Moor, Rousby High Moor, to the south of Ugthorpe. The strata on the whole dip to the north, though minor folds cause variations in their inclination; and the watershed is found to correspond almost with the axis of the synclinal trough holding the Kellaways Rock and forming the ridge of high ground from 700 to 800 ft. in height.

At the east end of the watershed are the two streams Mickleby Beck and Birk Head Beck running nearly due east to the sea at Sandsend. In the lower part of their course by Mulgrave Castle they run parallel to each other, but they occupy a single old Drift-filled valley and are only separated

by a narrow ridge of Drift (3), (8). The valley which they occupy is of considerable size and must have held in pre-glacial times a much larger stream. Its course is parallel to the synclinal of the watershed, and Mickleby Beck which rises seven or eight miles inland on Newton Mulgrave Moor follows the line of this old valley. Apart from its relation to the synclinal it is singularly independent of the dip of the beds. Several smaller becks from the high ground to the south flow down into Birk Head Beck.

At Runswick Bay there are several small streams flowing into the sea over the Drift, but none of any importance. But an old river-valley of considerable size enters the west side of the bay, and though now much filled with Drift can be traced in a north-easterly direction past Hinderwell to Dalehouse and on towards Easington. A boring near Hinderwell along its course went through 200 ft. of Drift without meeting solid rock. This valley does not appear to be dependent on the geological structure, and does not follow the synclinal axis which runs from Runswick to Skelton (8).

Borrowby Beck which flows to the N.N.E. along the line of an old pre-glacial valley, now filled with Drift, as far as Dalehouse, crosses here the above-mentioned valley and as Staithes Beck enters the sea by a narrow ravine of post-glacial origin (3), (8).

Easington and Rousby Becks which flow almost due north before turning to the north-east to join the head of the Staithes Beck at Dalehouse flow parallel to each other along the sides of an old Drift-filled valley with only a ridge of Drift separating them (3). The course of this old valley is in singular independence of the varying dip of the beds which it traverses.

The stream which runs into the sea at Skinningrove divides into two branches inland, one of which runs past Lofthouse in a rock-cut channel while its old Drift-filled valley is practically parallel to it. Liverton Beck which is the other branch is joined by Kilton Beck flowing north-eastward from the high ground of the main watershed. The latter beck has deviated considerably to the east of its pre-glacial channel, resulting in the formation of bold crags of Moor Grit on that side (8). Its

tributary, Hagg Beck, keeps mainly to its old course. All these streams traverse the rocks without the least dependence on the geological structure.

Skelton Beck which is a strong stream flowing north-eastwards in a deep wide valley, cut down from the Lower Oolites into the Middle Lias, is also independent of geological structure. The curious course of its upper branch, rising on Eston Moor and then after running north-east sweeping round the south flank of Upleatham Hill before again turning north-eastwards is noteworthy.

The great Boosbeck valley running north-eastwards, south of Skelton village, once held an important stream, but the head of it rising on Guisborough Moor is now diverted by Drift to the west at Slape Wath, and forms a stream flowing by the west side of Skelton Hill into Ellers Beck and thus to the sea (3), (8). The floor of the present valley of Skelton Beck was shown by a boring at Marske Mill to be 90 ft. higher than that of the old Drift-filled one (8).

Turning now to the Esk itself it is seen that the valley in which it flows in spite of its somewhat sinuous course has a general easterly direction, and though this is often stated to be along the general strike of the strata yet it is remarkably indifferent to the minor rolls which cross it and the consequent repeated changes of dip. Its general parallelism to the syncline to the north of it is sometimes quoted, but this correspondence is not very close. It crosses obliquely the course of the great Whin Sill more than once.

For the greater part of its course it flows over the Estuarine Series of the Lower Oolites, but here and there cuts into the Middle or Lower Lias, and the whole of its lower portion east of Glaisdale is over these beds. Its present true source is in the Kildale Gap, and it is obvious that the becks from Lonsdale on the north and Warren Moor on the south, which now fall into the Leven, formerly were its head branches. All the tributaries on its south side are in valleys excavated down to the Lower Lias. At West Wood near its head it receives from the north an affluent called Sleddale Beck coming down from Guisborough Moor, with its source near the edge of the escarpment.

At Scale Foot it receives from the south the important joint-stream formed by the union of the becks from Basedale and Westerdale. The Basedale beck flows due north from its source near Burton Howe in accordance with the dip of the beds, but after about three miles turns to the east and flows in that direction at right angles to the dip of the beds to the mouth of Westerdale, where it is joined by the two united becks from the two branches of Westerdale. Both these becks rise on Westerdale Moor on the moorland watershed, but the more westerly one, which is often called the head of the river Esk itself, flows in an irregular manner to the north-east independently of the dip of the beds, while the more easterly beck (Tower Beck) flows due north exactly down the dip of the beds.

The Esk runs eastward from Scale Foot in a somewhat meandering fashion to Castleton where it receives from the south Danby Beck issuing from Danby Dale and also agreeing in its direction with the dip of the strata. West of Castleton no Glacial Drift has been detected in the Esk valley (8).

Two small anti-dip streams fall into the Esk near Dale End from the watershed to the north; and a mile or so further east the Esk receives from the south the becks from the neighbouring and parallel dales of Little Fryup and Great Fryup. Both of these flow down the dip of the Oolites, and there is a curious pass from the head of Little Fryup Dale over into Great Fryup Dale which extends further south.

At Lealholm Bridge, a mile further east, the Esk flows through Crankly Gill in a steep-sided post-glacial gorge, only 150 yards across, and to the south of its much wider old valley which is three-quarters of a mile across but is choked with Drift (10).

Beyond this the general direction of the main valley is more to the south-east, and before reaching the mouth of Glaisdale it receives Stonegate Beck which flows due south as an anti-dip stream from the high moors on the north.

Glaisdale contains an important beck which runs in a general north-easterly direction into the Esk; and at its mouth the Esk has again been diverted from its old valley by a mass of Drift, and flows now through a narrow gorge which it has cut

through the solid Oolites between East Arnecliffe Wood and Egton Bridge. The old valley bends round the north side of Limber Hill.

Here the Esk valley is cut down into the Upper Lias, and for the rest of its course its channel is in Lias. At Egton Bridge the river regains its old pre-glacial valley, but its channel is still rather to the south side of it.

A small beck from Egton Grange dale with a north-easterly course enters it here, and further east at Grosmont the important tributary, the Murk Esk, falls into it. The Murk Esk flows almost due north from Beck Hole to its point of junction with the Esk, but above Beck Hole it forks, and the course of these branches will be described later.

From Grosmont the Esk flows to the north-east, crossing the anticlinal axis which runs north-west from Robin Hood's Bay (9) without being influenced by it. Between Sleights and Ruswarp the river follows nearly its old pre-glacial line of flow, but before reaching Whitby the old valley turns away to the north striking the coast to the east of Sandsend where the Drift forming the cliffs descends below sea-level. The present river runs in a more direct course to the sea by a steep-sided post-glacial gorge through the Lower Oolites following a line of fault near its mouth.

Between Ruswarp and Sleights, Little Beck enters the Esk from the south flowing down Iburndale from Sneaton High Moor without any reference to the dip of the beds or to the anticlinal axis which crosses it obliquely.

Between Ruswarp and Whitby the Esk receives Rigg Mill Beck flowing down from Fylingdales Moor in a N.-N.-Westerly direction. It follows roughly the general dip of the Estuarine beds over which it flows, and it enters the Esk valley nearly opposite the point where the old valley bends to the north-east.

The dales opening into the Esk valley on the south show so many points of interest that some further particulars may here be given with regard to the streams which they contain. The evidence for the occurrence of glacial lakes in some of them is being traced by other workers, but the present author has frequently noticed the terraces, etc. in the

course of his work, and it will probably be shown that the point of outflow has been temporarily or permanently altered in more than one case by the existence of glacial dams.

Minor alterations in the course of the streams in the more eastern dales have been caused by the irregular heaping up of the Drift, especially near their mouths, as in the case of Glaisdale.

The present course of the Murk Esk, as it is now found, is most curious, and an explanation of it is only possible by studying its history and relations to neighbouring streams. At Beck Hole near Goathland the union of two streams, one from the east and the other from the south, form the Murk Esk. The stream from the east is called Eller Beck and rises in May Moss on the outcrop of the Kellaways Rock, a long way to the south of the main moorland watershed and of the axis of the moorland anticline. From May Moss this stream runs at first north, then bends west where it is joined by Little Eller Beck from the east. It crosses then the head of Fen Bogs in Newtondale, and turns northward up this dale to Darnholm where it bends again sharply to the west to Beck Hole passing through a narrow gorge. The old pre-glacial valley which it followed lies to the south of this portion and follows the line of the old railway incline.

The southern tributary of the Murk Esk is Wheeldale Beck, formed by the junction of Rutmoor Beck and Blawath Beck, both of which rise south of the anticlinal axis. Rutmoor Beck curves round the south side of Wheeldale Moor, just north of the small synclinal of Trigger Castle and the outlier of Cornbrash preserved by it, and flows in a general north-easterly direction parallel to the strike, joining the anti-dip stream called Blawath Beck which rises from the foot of the Kellaways Rock escarpment and flows north-west. Wheeldale Beck thus formed runs north, receiving on its way the beck from Wheeldale Gill which runs eastward in a broad valley nearly along the anticlinal axis. Between Hazel Head and Beck Hole the course of Wheeldale Beck has been altered by the old valley being filled with Drift, and for part of the way the stream runs in a narrow post-glacial gorge.

The upper part of Little Beck in Iburndale is known as Blea Hill Beck and flows for a short way along the strike of the Blea Hill synclinal, but soon turns to the north-west and flows against the dip of the beds.

We may now turn to consider the drainage of the moorland region on the south side of the main watershed. As previously mentioned all the streams on this side, with the trifling exception of some near the coast, find their way into the present Derwent, and so through the Malton valley.

The most westerly of the dales is Ryedale. The river Rye rises on the Lower Oolites of Snilesworth Moor, and receiving several small affluents flows in a general south-south-easterly direction with the dip of the beds to the Tabular Range, the escarpment of which it cuts through just north of the village of Hawnby. Here it receives the small Ladyhill Beck, a dip-stream from the north, which separates two conspicuous outlying hills of Middle Oolite standing in front of the main escarpment. The river Seph from Bilsdale also joins it here, flowing between the eastern hill and the continuation of the main escarpment. The latter river occupies a much longer and wider valley above this point than the Rye, for it rises close to the very edge of the Lower Oolitic escarpment overlooking the embayment of Ingleby Greenhow. Its headwaters, formed by two streams, make two conspicuous notches in the edge of this escarpment, one on each side of the lofty hill called Hasty Bank, over 1300 feet high. The river Seph, thus formed, receives on the west about half-way down Bilsdale the important tributary, Raisdale Beck, which likewise rises on the edge of the escarpment further west and notches it conspicuously.

Further down, Ledge Beck enters the Seph on the east side, rising on Urra Moor and flowing south-south-west. These streams are all essentially dip-streams, and follow the general inclination of the beds. The Seph has cut down into the Lower Lias for the greater part of its course.

Below the point of union of the Seph and Rye the river, still called the Rye, flows down the dip of the Middle Oolites in a general south-easterly direction to Helmsley, making a remarkable curve northwards shortly before reaching that

place. Beyond Helmsley the Rye flows across the undulating Drift-covered ground of the Vale of Pickering, south-east to Nunnington and thence eastwards along the northern foot of the ridge of Middle Oolites which dip north, to join the Riccal at Waterholmes. From here it meanders over the level ground with a general easterly course to unite with the Derwent at Rye Mouth near Wykeham, receiving on its way, first, Hole Beck running due east from Gilling Gap, and then, the more important Wath Beck from the Howardian Hills to the south. On the north side it receives the rivers Dove and Seven, and Costa Beck from their respective dales.

Wath Beck is interesting because while having a general north-easterly course agreeing roughly with the main dip of the beds in the Howardian Hills, it is quite independent of the faults which cross its channel at all angles.

East of Helmsley there are several small dip-streams rising on the Tabular Hills and cutting small valleys in them down to the Vale of Pickering.

The next important dale is that of the Riccal, but it is much shorter than Ryedale or Bilsdale, the river Riccal rising only on Helmsley Moor, two or three miles north of the escarpment of the Tabular Hills on the Lower Oolites, and not cutting down into the Lias. It ultimately joins the Rye in the Vale of Pickering, as above mentioned.

Bransdale is the next valley to the east, and this is a large and long one, excavated down to the Lower Lias and occupied by Hodge Beck. It runs down the dip of the beds, and cuts through the Middle Oolites west of Kirkby Moorside, issuing then into the Vale of Pickering where it falls into the river Dove from Farndale.

Farndale, which is one of the largest dales, reaches right up to the main moorland anticlinal axis and is cut down into the Lower Lias. It is occupied by the river Dove which runs down it in a general south-south-easterly direction with the dip of the beds, and is joined on the east by Blakey Gill, coming down south from Blakey Moor, and lower down on the west by West Gill. The Dove enters the Tabular Hills through a fine gap in the escarpment at Gillamoor, and

immediately on issuing from them turns to the south and is joined by Hodge Beck before running south-eastwards into the Rye.

Between Farndale and Rosedale, which is the next large dale to the east, there are several small streams rising on the Estuarine beds of Spaunton Moor, and cutting through the Tabular Hills. These are all dip-streams for their whole course, except Lastingham Beck, which beginning as a dip-stream turns eastwards at the foot of the escarpment and runs as a strike-stream to join the river Seven from Rosedale.

Rosedale is a dale similar to Farndale, but with a more pronounced trend to the south-east. In fact it is slightly oblique to the dip of the beds in that part of its course north of the Tabular Hills. It is deeply cut down into the Lias and is occupied by the river Seven. It has a tributary, Northdale Beck, which flows southwards into its middle portion, and after leaving the Liassic valley it receives another, flowing in a generally similar direction and known as Hartoft Beck. Thus reinforced the river Seven cuts through the Tabular Hills almost at right angles to the strike of the beds and as a true dip-stream, and it maintains this direction across the Vale of Pickering till it falls into the Rye.

East of Rosedale there are no more similar wide dales of a simple nature running to the south or south-east. The escarpment of the Tabular Hills makes here a great bend to the north-east, and the whole outcrop of Middle Oolites much increases in width at the expense of the Lower Oolites. The outcrop of the Kellaways Rock begins to cover a large superficial area at the foot of the main escarpment, and the Rock itself rises as a marked step or subsidiary escarpment above the moors to the north. The small becks, Sutherland and Cawthorn Becks, run south-westwards at the foot of this escarpment and are joined at New Bridge by the small parallel stream to the south-east which flows first from its source at the foot of the escarpment of the Lower Calcareous Grit as a strike-stream and then turns northwards across the strike of the beds. Sutherland Beck at Fall Rigg falls into Little Beck, which is a true dip-stream and joins the Seven.

The next stream to the east is Stape Beck which crosses the Kellaways Rock outcrop and enters Newtondale where it joins the stream flowing south-east to Pickering. Stape Beck is a true dip-stream, though slightly irregular; and so is Pickering Beck from its point of junction with it to Whinnymoor where it turns to the south-west and flows in this direction to the town of Pickering, obliquely across the general dip of the beds. About a mile above Pickering it receives on the north the true dip-stream called Gundal Beck.

It should be mentioned that on Scalla Moor which forms the southern bank of the lower portion of Pickering Beck the direction of dip of the Middle Oolites agrees very closely with the trend of this part of the stream.

The upper part of the Newtondale stream (Pickering Beck) has a curious course and interesting history (3) (see pp. 71, 72). It rises in Fen Bogs in the middle of the continuous valley which in its northern portion contains Eller Beck. From Fen Bogs the stream flows irregularly southwards across the wide outcrop and against the dip of the Kellaways Rock of Fen Moor. At Eifel Head it turns to the south-west, and runs along the strike of the beds and under the escarpment of the Lower Calcareous Grit to the point where Stape Beck enters Newtondale, south of which its course to the Vale of Pickering has been described above. It crosses the Vale joining Costa Beck near Kirkby Misperton and is thus conducted into the Rye near Wykeham.

A small anti-dip stream enters it at Eifel Head, and between Stape Beck and Whinnymoor the dip-stream from Levisham enters it on the left.

Thornton Dale with Staindale at its head is the next valley of importance to the east. The courses of these dales and of their small branches are singularly irregular, and they ramify over the Corallian beds in a remarkable manner.

The main direction of Staindale is W.S.W., while that of the upper part of Thornton Dale which it joins is almost due south, and the lower part again W.S.W. The slight rolls in the strata occurring along its course (9) do not seem to affect it, nor yet the fault at Ellerburn. All its tributaries come in

on the east side, and along part of its course the stream (which in Thornton Dale is known as Dalby Beck) has cut down into the Oxford Clay. The bend to the west in the lower part of its course recalls that of the neighbouring Pickering Beck at Whinnymoor and suggests a common cause.

The stream ultimately joins the Derwent in the Vale of Pickering.

Between Thornton Dale village and East Ayton at the mouth of the Forge Valley there are many small streams following closely the direction of dip of the strata, and flowing down into the Vale of Pickering, so as to drain the southern slopes of the Tabular Hills. The villages of Allerston, Brompton, Wykeham and West Ayton are situated at their mouths. The curious lower course of Sawdon Beck and Beedale Beck above Wykeham suggests diversions caused by Glacial Drift.

We have now come to the district where the various head-waters of the Derwent arise. They issue out of several dales around and within the Hackness synclinal. The stream which is usually considered as the actual head of the Derwent rises on Lilla Rigg close to the foot of the Kellaways Rock escarpment, and runs parallel to it in a south-easterly direction to the head of Langdale where it receives Lownorth Beck from the east. The Derwent then turns down the narrow straight valley of Langdale which follows the dip of the beds which is here almost due south. It cuts off a narrow strip (Langdale Rigg) from the west side of the Hackness outlier, and about half a mile south of the village of Broxa receives Black Beck which is formed by the union of several becks (Hipper Beck, Stockland Beck and Grain Beck) rising on Allerston High Moor and Wykeham High Moor on the broad outcrop of Kellaways Rock and running in a south-easterly direction. Black Beck is, however, partly a strike-stream flowing past Cross Cliff and North Side along the foot of the escarpment of the Lower Calcareous Grit.

About a mile below the point where it receives Black Beck the Derwent receives Troutsdale Beck which flows to the north-east down the important valley of Troutsdale.

At this point the Derwent enters a wide valley and bends eastward to Hackness across the dip of the beds. Here it again bends to the south-east, and then, instead of turning north-east along the broad valley of the New Cut which stretches away towards Scalby, it cuts southward directly through the rest of the Tabular Range by the narrow steep-sided gorge known as the Forge Valley.

The Forge Valley itself is only 400—500 yards wide while the valley of the Derwent above it is 1100 yards wide (3). The character of the rocks has certainly not been the main cause of this change of size. But whereas the New Cut Valley is strewn and partly choked with Drift the Forge Valley is free from it, and herein lies a clue to the problem (see p. 88).

At Ayton the Derwent issues into the Vale of Pickering, and at first meanders southwards, but turns to the west after 3 or 4 miles and flows in that direction along the centre of the Vale of Pickering with a sinuous course, receiving the river Hertford from the Drift-filled mouth of the Vale at Filey, and the numerous streams from the dales on the north which have been described.

Before following the course of the Derwent out of the Vale of Pickering it will be as well to turn back to Lownorth Beck which was mentioned as entering the Derwent at the head of Langdale.

Lownorth Beck is the lower part of an important group of becks which have their most northern source at Foul Sike about 4 miles inland from Robin Hood's Bay. From here runs Biller Howe Dale with its beck continued in a south-easterly direction as Jugger Howe Beck across the Lower Oolites but irrespective of the dip and rolls in the beds.

At Burn Howe Moor it is joined by Helwath Beck, which seems to be a true dip-stream and flows south. The Jugger Howe Beck from this point flows southward in a continuation of the Helwath Beck valley to the base of the Middle Oolite escarpment of Hackness Moor where it turns west and flows along its foot as a strike-stream to join the Derwent at High Langdale End, this westerly-flowing portion being known as Lownorth Beck.

A valley much blocked with Drift runs to the south-east towards Scalby under the escarpment of Suffield Moor, and is called the East Syme.

Returning now to the Derwent in the Vale of Pickering we see that it is joined by the Rye near Rillington Moor, and runs then south-west to Malton where it cuts through the Howardian Hills against the dip of the beds. The valley is wide for the first half of the distance which is as far south as High Hutton, but here it enters a narrow gorge, and after about a mile and a half turns sharply to the north-west along a line of fault and along the strike of the Oxford Clay as far as Firby Wood where it again turns to the south-west, and after another bend to the south-east and a final one at Crambe to the south-west it issues into the plain of York. At Kirkham where it runs through the gap in the Oolitic escarpment the edge of the escarpment is from 200 to 250 ft. high (3).

After a meandering course in a general southerly direction along the strike of the Trias the Derwent falls into the Ouse at Barmby-on-the-Marsh.

Returning to the east end of the Vale of Pickering there are only a few small streams east of the Forge Valley which flow into the Derwent, and they are all dip-streams. The stream down the Seamer Valley, and the one from Deep Dale may be mentioned.

From the east end of the Vale of Pickering come the River Hertford and the New Hertford River flowing westwards into the Derwent along the synclinal trough of Kimeridge Clay.

Practically none of the drainage of the northern edge of the Yorkshire Wolds falls into the Vale of Pickering. Scrampston Beck which issues from the large embayment in the Chalk escarpment between Wintringham and Thorpe Bassett and flows north-west into the Derwent is the only stream of any importance, and its direction is against the dip of the Chalk.

Where the Chalk escarpment crosses the strike of the Oolites of the Howardian Hills several small becks are found, running west or north-west from the neighbourhood of North Grimston. Of these may be mentioned Menethorpe Beck and

its head streams from the foot of Birdsall Wold, joining the Derwent at Menethorpe village.

South of the Malton Valley the Chalk escarpment sheds back into the Triassic valley many small anti-dip streams, which need not here be particularised.

We may now turn to look at the drainage of the coast between Whitby and Filey. It is mostly effected by short streams running direct into the sea.

Of the group of becks emptying into Robin Hood's Bay the most important is Mill Beck rising several miles inland near Foul Sike and running in no direct relation to the dip of the beds or anticlinal axis.

At Hayburn Wyke a true dip-stream, flowing down Staintondale and belonging to the same category as Helwath Beck and others to the west, enters the sea.

Between this point and Scarborough are several small becks emptying into the New Cut river, and flowing over the Drift-covered ground.

The small streamlets draining the cliffs south of Scarborough call for no mention here.

With regard to the Chalk area, most of the present drainage of the Wolds is effected by the river Hull which runs southwards into the Humber.

CHAPTER V.

THE HISTORY OF THE RELATIONS OF THE RIVERS TO THE GEOLOGICAL STRUCTURE.

THE relations of the water-courses of such an area as East Yorkshire to its geological structure must necessarily be complex, as the history of the area has been varied, and adjustments of different kinds have been produced.

There are four classes of drainage modifications which may be recognised to have occurred in this region. There are, firstly, adjustments due to the characters of the rocks and geological structure; secondly, adjustments marking the progress of a river through a normal cycle of development; thirdly, adjustments caused by movements of elevation or depression; and fourthly, changes induced by glaciation, especially by the deposition of Glacial Drift.

The special subject of study is adjustments of the first class, but the effects of the other processes and the interaction of them all cannot be neglected. It is necessary to take them all into account in tracing the dependence of the water-courses on the geological structure.

We must go back to the earliest stage in the initiation of the drainage-system. The original 'constructional' surface on which the primary consequent rivers were initiated consisted of Cretaceous strata, as we have seen there is reason to believe. The post-Cretaceous and early Tertiary uplift was regular and simple, tilting the Cretaceous beds gently to the east or south-east, and together with the marine erosion which took place during the upheaval producing a slightly inclined surface dipping in the same direction. The direction of the original consequent streams was thus determined irrespective of the more complicated

structure of the subjacent Jurassic and other rocks buried beneath the unconformable cover of the Chalk. Therefore, though these consequent rivers would be in direct relationship to the then-existing surface conditions, they would be more or less independent of the structure of the underlying platform into which they would subsequently intrench themselves. When the Cretaceous cover had been removed their dependence on the geological structure (*i.e.* the simple dip of the Cretaceous beds) of the surface on which they originated would not be obvious, and subsequent adjustments to the new conditions might completely conceal it.

We must therefore suspect the existence of a more or less 'superimposed' (22) (24) or epigenetic (23) drainage-system from the geological history of the region.

Moreover all the important rivers of this district are seen to be "composite" (using Davis' terminology (25), (26)), *i.e.* they drain districts of divers structures and geologically distinct; they are also "compound," being formed by the union of portions of various ages, as will be shown later; and finally they are "complex," having been through more than one cycle of development, as the Tertiary and post-Tertiary history of the region suggests.

It is impossible to say with certainty whether the Cretaceous cover was not partly removed by the marine erosion which took place during the progress of the upheaval, particularly from the places where it was probably thinnest, as for instance, over the crest of the Jurassic anticlinal. But it scarcely affects the main contention that a Cretaceous cover at first existed, though the subsequent exposure of the ridge of hard Jurassic beds trending east and west may have had something to do with the more easterly course of some of the original consequents, especially if it was exposed somewhat early in the process of general surface-lowering.

According to some geologists *marine* erosion is responsible not only for the complete planing off of the whole of the Cretaceous rocks but also for the production of a 'plain of marine denudation' (28), of diverse stratal composition, a surface in fact upon which outcropped the Jurassic and all the

older rocks; and as a relic of this old marine level of erosion they would point to the even-topped uplands (2). The regular level of the dissected tableland may however be explained as a 'peneplain,' or base-level of erosion produced by *subaerial* denudation as the penultimate result of the complete development and old age of a drainage-system (1).

It is not necessary to discuss here the relative merits of these views; but it may be remembered that the chief fact on which Davis (1), the advocate of the peneplain, lays stress as favouring his theory that the uplands of Oolite and Chalk in the east of England are the remnants of an old land-surface levelled by subaerial agents, is the strong development of subsequent streams.

There is some evidence of certain of the streams being 'superimposed' (24), for they are almost independent of the geological structure of the district which they traverse; and this feature in their behaviour suggests that their immediate ancestors may have developed on an unconformable cover of Cretaceous rocks.

The present drainage-system may therefore be held to be either (i) the successor of a pre-existing one which developed on a more or less continuous and uniform Cretaceous cover, and which ultimately produced a peneplain of diverse stratal composition, now uplifted into the table-land and dissected by later drainage; or (ii) to have developed *ab initio* on an elevated 'plain of marine denudation,' of diverse stratal composition. Davis (1) supposes that such a plain of marine denudation must have had a cover of marine sediments spread over it in the course of its formation, and that upon this cover the new drainage-system would be developed in complete independence of the structures beneath. But such a cover might be completely removed during the uplift. Attention may here be drawn to the fact that the length of time requisite for the reduction of a land area to a 'plain of marine denudation' would be enormously greater than that for the production of a subaerial peneplain, assuming that no earth-movements occurred and that the relative rates of marine and subaerial denudation were much the same as at the present day.

There is much in favour of regarding the uplands as representing an uplifted peneplain, apart from the strong evidence of the rivers adduced by Davis (1). Thus the early Tertiary uplift which affected the British Isles appears not to have been followed in the north of England by a depression sufficient to allow the deposition of Eocene and Oligocene beds of similar character to those in the southern counties; indeed the northern area seems to have remained as land during their accumulation, and during this time it must have suffered extensive denudation. This would be the period of the formation of the peneplain.

The original land surface sloped to the east or south-east (1), and accordingly the general direction of the primary consequent streams was thus determined. To what extent the other water-courses were developed is more or less a subject for speculation, but if the general level of the surface of the peneplain is restored by reference to the flat-topped uplands, it will be evident that neither the Vale of York nor the Vale of Pickering could have existed in their present state at the close of this first cycle of denudation.

All the cutting down of the rivers into the surface of the peneplain and the fashioning of the present topographic features were effected by the revival of the rivers owing to the Miocene uplift.

It is, however, certain that some adjustments to structures had taken place before this Miocene elevation, because of the perfection of the present state of the adjustments (1).

We have also no reason to suppose that the surface of the sub-Cretaceous platform stood at first at the same height above sea-level as the surface of the peneplain which was produced upon it; *i.e.* nearly at the base-level of erosion. The platform probably was at a considerably higher level than the surface of the peneplain to which it was only reduced after a long course of subaerial denudation, as the following diagram (Fig. I.) illustrates.

The outcrops of the various Jurassic and older beds must accordingly have produced some modifications in the course of the rivers in pre-Miocene times, as, for instance, the beheading of some consequent streams by the subsequent branches of others. The original epigenetic character of these rivers would by these

processes be lost or considerably obscured before the close of the first cycle. The presence of epigenetic characters in the

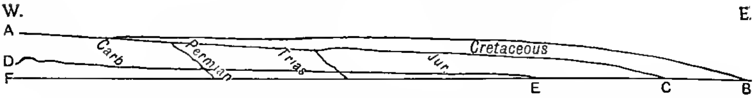

Fig. I. *Diagram of sub-Cretaceous platform and original constructional surface. (Vertical scale exaggerated.)*

AB. Original constructional surface on which rivers originated.
AC. Surface of sub-Cretaceous platform.
DE. Surface of peneplain produced by subaerial denudation.
FB. Sea-level.

existing drainage-system is too feebly indicated to allow us to hold that such features were strongly preserved into the second cycle, *i.e.* till after the Miocene uplift. We do not find any general independence of the geological structure in the behaviour of the water-courses, as would otherwise be the case.

In seeking for traces of the pre-Miocene water-courses we must first look for the original consequent rivers which would maintain their general direction and persist after the commencement of the second cycle. Their direction had been determined by the original slope of the constructional surface and was approximately at right angles to the strike of the beds, though local irregularities and warpings in the process of elevation in early Tertiary times may have caused minor modifications. We may conclude with Davis (1) that this slope and direction of flow was to the east or south-east, as the general dip of the Mesozoic beds indicates.

The rivers which have this general direction and can be traced across the area breaching the escarpments may be regarded as the representatives and direct successors of these original consequents. Owing, however, to later processes of capture and diversion their courses are now rarely continuous, and we find them broken up into several disjointed portions. Their upper portions are generally the most distinct.

In the region with which we are dealing the upper portions of the Tees, the Swale, the Ure, the Nidd, and the Wharfe west of the Triassic outcrop, and the continuous Aire-Humber

are seen to correspond with the requirements and to follow the slope of the original constructional surface. Their middle and

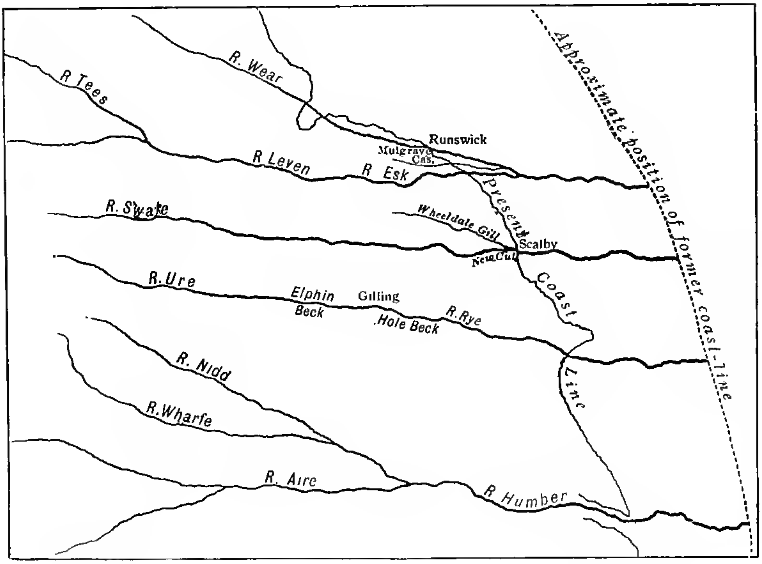

Fig. II. *Diagrammatic Map, showing course of original consequent rivers at commencement of 1st cycle.*

lower portions are not always easy to discover owing to subsequent adjustments, but in some cases are fairly obvious.

Davis (1) thinks that the representatives of the middle parts of some of these original consequents should be found in the Rye, Riccal, Dove and Seven rivers, and that their lower portions should have left traces on the eastern slope of the Yorkshire Wolds from Great Driffield to Hull. But he has attributed to these rivers a more south-easterly course than their present upper portions warrant. The general direction of the Swale and Ure west of the Triassic outcrop is almost due east, and of the Tees east-south-east. The Nidd, Wharfe and Aire west of the same outcrop indeed pursue a south-easterly course, but if this direction was continued across the Vale of York it would bring them considerably south of a line drawn from York to Beverley.

The direct field evidence of the easterly continuation of the Tees, Swale and Ure will be given later; and it will be shown that there is nothing to make us suspect that they followed such a course as Davis suggests.

In order to find the continuation of original consequents the line of direction preserved by the upper portion must be prolonged across country; and it is along this line that we must search for traces of their middle and lower portions.

The formation of consequent rivers leads to the growth of lateral affluents which take the form of longitudinal or 'subsequent' streams along the strike of the strata in a region of simple structure consisting of regularly and gently inclined bands of strata of varying hardness (29), (31). In the first cycle the cover of unconformable strata would be first removed from the upper part of such a region as ours, since the upper portions of the structural curve are more exposed to subaerial denudation. By thus planing off these upper portions the edges of successive strata are uncovered, for the dip of the beds always remains greater than that of the land-surface (26). A succession of outcrops allows the exhibition of differences in texture, hardness and resistance, the harder bands standing out in relief, while the softer ones are worn away into depressions; and it is evident that in these depressions will tend to be formed the first lateral affluents of the consequent streams. Such affluents would first be developed in our region along the Triassic outcrop.

The development, therefore, of subsequent branches to the original consequent rivers proceeds by the normal progress of erosion.

By the deepening of the trench in the soft rocks the bordering hard bands stand out more and more in relief and form escarpments, and the so-called 'step-structure' is initiated in the topography.

The original consequent streams will from the first differ in size and strength. The larger ones will deepen their channels more quickly than the smaller ones; and the lateral subsequent branches of the larger consequents will accordingly grow more rapidly headward along the strike of the soft beds than the

corresponding branches of the smaller consequents. As a result the strongest and most rapidly growing subsequent will abstract the upper portions of the smaller and weaker consequents; and the originally stronger consequent stream will increase in strength and persist as a continuous stream while the others are now divided into two sections, the lower one of which is termed 'beheaded.' Between the 'elbow of capture' and the head of the 'beheaded' lower portion an 'anti-dip' or 'obsequent' stream is formed which drains back into the strike valley along the line of the old beheaded consequent, (1), (22), (27), and may in time attain a considerable size and importance.

The foregoing considerations regarding the growth of subsequent streams and the features of beheaded consequents will enable us to interpret some of the leading characters of the drainage-system of our region.

The upper portions of the original consequents known now as the Swale, Ure, Nidd, and Wharfe enter the Triassic outcrop through the Magnesian Limestone escarpment, and suddenly make a bend to the south, forming the Ouse which flows southward into the Humber. The sudden bend indicates that they have been successively captured by a strong subsequent working headwards to the north; and this subsequent is now represented by the Ouse which is a lateral affluent of the Aire-Humber original consequent.

The success of this subsequent in capturing the other consequents points to the Aire-Humber having been the strongest original consequent of the group.

North of this group is the Tees, an original consequent which on entering the Triassic outcrop turns north-eastward along the strike of the softer beds. This consequent, therefore, was beheaded by an entirely different subsequent—a lateral affluent of some consequent to the north. The subsequent worked back southwards along the Triassic outcrop, parallel to that which similarly diverted the consequent Wear along a valley on the west of the Magnesian Limestone.

Now in order to find the continuation of such original consequents we must prolong their upper portions in their

general direction of flow across country; and by doing so in these cases we see where we ought to look for traces of their middle and lower portions.

Granting, however, that the Tees, Swale, Ure, etc., west of the Triassic valley represent the upper parts of original consequents, we have still to decide whether their capture and abstraction were performed during the first cycle or at a later period, *i.e.* during the formation of the peneplain or after the Miocene uplift.

It is therefore necessary to consider the tests which can be applied in order to fix the date of the abstraction or beheading of consequent streams while we are engaged in the search for their middle and lower portions. The following tests suggest themselves:

(1) If the continuation of the general direction of the course of the upper portion brings one along a distiuct valley possessing the same trend and excavated in the surface of the peneplain, we may be inclined to conclude that the abstraction did not take place till after the revival of the consequent, that is, till the second cycle. But this conclusion may be incorrect (see below).

(2) If on the other hand there is no such valley across the peneplain which could correspond with the prolongation of the upper portion of a beheaded consequent, we may conclude that the abstraction took place before the second cycle commenced, so that there was no continuous consequent in existence after the uplift to cut into the elevated peneplain during some portion of the second cycle, as there was in the preceding case.

The absence of a gap or notch in the escarpment opposite the point of entry of the upper portion into the subsequent valley would support the latter conclusion.

But there are several qualifications necessary. For instance, the gap by which a continuous consequent river after revival cuts through a growing escarpment before abstraction may be obliterated by recession of the escarpment and by general surface-lowering.

The strong development of an 'obsequent' or anti-dip stream is generally considered to mark the beheading of the consequent in a previous cycle (1). The gap in the escarpment will be kept open and perhaps even deepened by the headward growth of the obsequent, and the latter may in its turn effect captures of other streams (*e.g.* the Leven in Kildale, see p. 74).

Again, the lower portion of a consequent abstracted in the first cycle may be represented by a revived stream of considerable size in the next cycle or later, especially if it receives some important affluents. It may even grow headwards again and effect captures. Local and special circumstances of geological structure may also favour its development. Thus test No. 1 may prove to be insufficient.

The consequent streams in our region which persisted from the first cycle with a continuous course and were revived by the Miocene uplift would proceed to intrench themselves in the peneplain as it was elevated to a higher level, cutting gaps in the transverse hard beds which by differential erosion were becoming escarpments. When their upper portions were abstracted by subsequent streams their lower portions would persist in their original valleys more or less intact. A continuous valley would be traceable from the source of the consequent to its mouth, interrupted by transverse 'subsequent' valleys, and containing two or more distinct streams, the number of which would depend on the number of abstractions which had been effected. Some of these streams would flow in an opposite direction to the original continuous consequent, being anti-dip or obsequent (1) streams. Such broken-up valleys have been noticed in other parts of England (27).

We must beware, however, of regarding all gaps in escarpments as indicating the former passage of a continuous consequent, for the breach may be due to the wearing away of the collecting ground of a stream on the back of the escarpment by the recession of the latter (*e.g.* Bilsdale). No corresponding stream representing the headwaters of such a consequent is in this case to be found on the opposite side of the valley in which the abstraction might have occurred.

In the case of the Tees the original consequent may be

considered to be now represented (i) by the Tees itself as far down its course as Yarm, (ii) by the Leven, an obsequent from Kildale, (the meanderings are due to later changes), and (iii) by the Esk. In spite of modifications in the course caused by Drift-deposits, etc., the general line of this original consequent is well preserved, and it is obviously epigenetic, though the existence of the Moorland anticlinal may have prevented the Esk from subsequently wandering from its course. The independence of the geological structure of the ground which is shown by the Esk is strong evidence of its origin epigenetically in a former cycle.

In the case of the Swale there is no breach in the escarpment opposite its entrance into the Triassic valley, and no middle portion on the moorlands, but it is possible that the valley of Troutsdale with that part of the Derwent valley between this dale and the entrance to the Forge Valley, and the New Cut Valley to Scalby may represent its lower course. It is on the other hand possible that the Swale was from the first only a head-branch of the Ure and joined it long before reaching so far east, perhaps following approximately the course of the present Rye, and that it never entered the sea independently. If this latter supposition is correct the above-mentioned portion of the Derwent with Troutsdale and the New Cut Valley, so strikingly independent of the geological structure of the Jurassic platform, may be the remains of a short original and superimposed consequent which did not have its source so far to the west as the Swale, Ure, etc. It does not seem possible to decide which is the correct interpretation; but that this portion of the Derwent, etc., represents the lower portion of some original consequent there does not appear any reason to doubt.

With regard to the Ure as an original consequent we may recognise as its disjointed representatives (i) the Ure itself as far east as the Triassic plain, (ii) the obsequent Elphin Beck from Gilling Gap, (iii) Hole Beck, (iv) part of the Derwent in the Vale of Pickering, (v) the upper part of the obsequent Scrampston Beck from the wide gap in the Chalk escarpment near Wintringham, and (vi) the dry gravel-strewn valley running east from this point across the Wolds towards Bridlington.

The Nidd and Wharfe were probably tributaries of the Aire-Humber and joined the latter before reaching the sea.

The Aire and Humber together represent the strongest original consequent of the whole group, and its subsequent branch, now represented by the Ouse, successively captured, as it developed headwards, all the other consequents to the north, except the Tees.

With regard to the date of these captures we should expect the nearest consequent, the Wharfe, to be captured first, and then the others to the north successively. But it seems probable

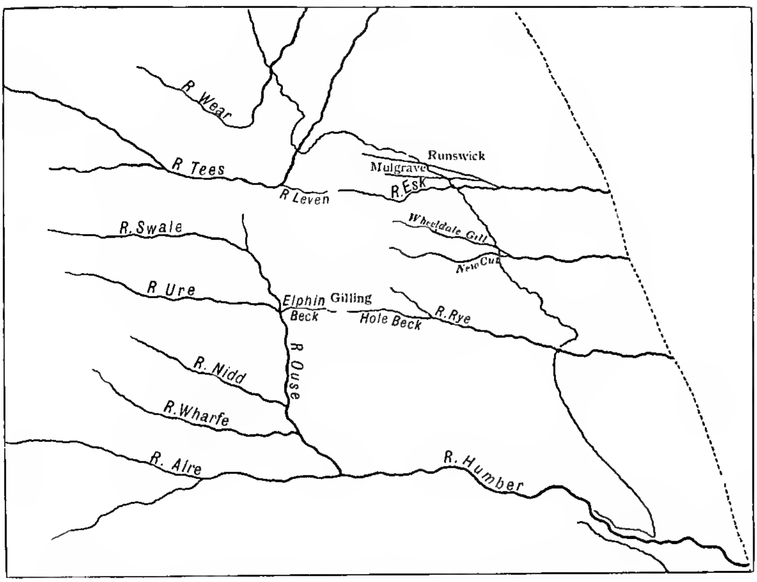

Fig. III. *Diagrammatic Map, showing principal water-courses at close of* 1*st cycle.*

that a subsequent branch of the Ure captured the Swale sometime before the Ure itself was captured by the Ouse. Otherwise the Swale would have been the last consequent to be captured, and consequently ought to have left strong traces of its former course east of the Triassic valley; and we should expect to find a strong obsequent and a marked representative

of its lower portion with the same relations as those which the Esk and Leven have to the Tees.

The Ure, when once it had cut through the Cretaceous cover along its middle portion, would find the easily denuded Kimeridge Clay below, and the downward cutting of its channel would be specially facilitated by the faulted tongue of the same soft rock in the Gilling Gap, whereas the Swale would meet with the tougher beds of the Lower and Middle Oolites and could not excavate its channel at so rapid a rate. The subsequent branch of the Ure would therefore soon capture the upper part of the Swale; and if this abstraction took place ere the latter had cut a channel of any depth in the Jurassic platform the traces of its former presence would be very slight, and no obsequent would be developed.

If we consider that the New Cut, etc. (p. 64), represent its lower portion, we must conclude that its lower portion persisted and was revived in the next cycle. We may, however, see in the New Cut, etc., the revived remains of a short original consequent, the head of which was from the first situated east of the Triassic outcrop; but the former view commends itself more to the author.

By the application of the tests previously mentioned we may conclude that on the surface of the pre-Miocene peneplain during the first cycle the subsequent Ouse captured the Wharfe and Nidd and finally the Ure which previously had captured the Swale. Further north the Wear had been diverted by a subsequent below the Magnesian Limestone escarpment, and the Tees had similarly been captured by a subsequent working southwards along the outcrop of Trias. The obsequent streams of the Tees and Ure had begun to be developed from the face of the Jurassic escarpment (Fig. III.). It is not imagined that the level of the Jurassic platform under the Cretaceous cover coincided at the first with the base-level of erosion when the original constructional surface was formed; the platform stood undoubtedly at a considerably higher level, and was reduced to a lower level by the formation of the peneplain. Accordingly, in this process of reduction, and in fact as soon as the Cretaceous cover had been removed, the differences of hardness, etc., in the beds composing the platform began to express themselves.

Thus an outcrop of Kimeridge Clay trending east and west would be exposed on the south side of the moorland anticlinal—between it and the Chalk—and along this would develop a subsequent flowing eastwards with the general slope of the surface, and at the foot of the Chalk escarpment. This subsequent would be more or less parallel to the original consequents.

At the conclusion of the first cycle the whole area was worn down to low relief, but the streams did not lose all traces of their adjustments (1); and when the second cycle was initiated by a strong uplift they were for the most part revived. As Davis (1) has remarked a considerable share of the new drainage would be along the revived subsequent streams; and the Ouse therefore would at once advance into primary importance.

The relative level of the land with regard to the sea must have been considerably lower at the end of the first cycle than it is now, for the present land-surface does not approach the condition of a peneplain, and is high above the base-level of erosion. It is however probable that the land extended further to the east than it does now, in spite of a further extension having been given to it by the Miocene uplift; for the recession of the cliffs by marine erosion since then has been of great extent, and the North Sea was not formed till the Pliocene subsidence, as previously mentioned.

The surface of the peneplain would not be an absolute level; isolated elevations and ridges would be left standing owing to the incomplete planation, but it does not seem likely that any of the present Oolitic escarpments which trend from east to west had been developed.

The escarpments stretching north and south had been developed by the growth of the subsequent streams, but had been again reduced to low relief; their position at the close of the 1st cycle must have been somewhat further to the west than they are at present and their course also straighter, as Davis has pointed out (1).

By restoring the general level of the region to that of the present uplands (which represent approximately the surface of the peneplain) the position of the outcrops of the various strata

and the amount of their subsequent lateral shifting owing to the progress of denudation by the revived and newly initiated rivers can be approximately determined; and it will show the character of the surface on which the Miocene drainage was developed.

This Miocene elevation was not of quite a simple nature, nor of the same amount over the whole area. There was a special axial elevation along the line of the old Moorland anticlinal—the pre-Cretaceous line of folding; and along this east and west line the peneplain underwent a maximum uplift. The deformation thus produced in the surface of the old peneplain gave rise to a new watershed more or less parallel to the direction of the original consequent streams; and it gave also a southerly dip to the Cretaceous beds on its southern flanks. The general slope of the surface of the whole area to the east was preserved, though its gradient may have been increased.

The amount of deformation of the peneplain is shown by a tabulation of the heights of the uplands in section from north to south, and its general slope by a tabulation of those from east to west (Fig. IV.). Phillips (2) noticed these facts, but did not draw the above deduction from them. The actual amount of the upheaval is difficult to calculate exactly, but the result of

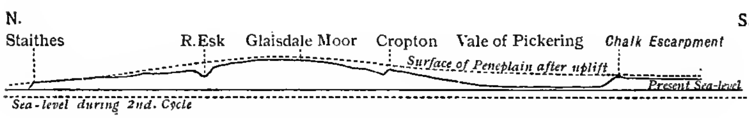

Fig. IV. *Diagrammatic section illustrating deformation of peneplain by axial uplift at commencement of 2nd cycle.*

Length of section 35 miles.
Vertical scale about 4000 feet to 1 inch.

———— Present surface of ground.
············ Surface of peneplain after uplift.

the movement was that the surface of the land stood at a considerably higher level than that at which it does now. The depth of the buried valleys, now 50—100 ft. below sea-level proves this; and if we take into account the general lowering of the surface by subsequent denudation we shall not certainly overestimate the amount at 200 ft. If therefore we add this

amount to the height of the uplands as we now find them we get some idea of the magnitude of the elevation.

We have no reason to suppose that any interval occurred between the 1st and 2nd cycles, or that the movement was sudden and of brief duration. The uplift commenced in late Oligocene times (see *antea*) and probably did not end till after the Miocene period had begun. The general processes of denudation went on with increased energy during the upward movement, but as the rate of elevation exceeded that of erosion the surface of the land at the conclusion of the uplift stood at a much higher level than it did when the movement began. The revived streams also did not keep pace with it in their downward corrasion, so that when the area became stationary again they had not reached the base-level of erosion, but had excavated deep channels in the surface of the old peneplain, which were of the nature of cañons (3) where the beds were of a suitably hard character.

The slight deformation (Fig. IV) of the surface of the peneplain by the axial uplift produced a new watershed nearly at right angles to the old one, and thus initiated a new set of secondary consequent streams on each side, running respectively north and south with the dip of the beds but slightly trending to the east in each case owing to the general slope of the surface in that direction. A wide strip of 'coastal plain' (1) was added to the land by the general movement of elevation, but this has been lost by subsequent subsidence and marine erosion.

Since during this second cycle all the main topographic features of this region were developed, and most of the remaining river-adjustments were produced, it is necessary to give special attention to this period.

In the first place the revival of the original consequent streams led to the deepening of their channels in the surface of the peneplain.

It has been pointed out that there is much probability that the beheading of the longer consequents by the subsequent Ouse along the Triassic outcrop had all been effected before the Miocene movement, and that only the successful Aire-Humber preserved an unbroken course.

The Ure, however, probably persisted for some time east of Gilling Gap as a continuous stream, and cut a considerable valley into the surface of the Wolds, for it received new life and energy by the tributary secondary consequents from the west end of the new moorland watershed, its volume increasing by the addition of their waters. It may also have received some affluents from the south from the slopes of the Howardian Hills as they rose into eminence by the lowering of the ground on each side of them.

The subsequent history of this portion of the Ure will be followed later.

Looking at the revived rivers further north we see that the subsequent Ouse continued to develop headwards up the Triassic valley as the river Wiske; and if the influence of the axial uplift of the peneplain extended as far west (as indeed is most probable), the watershed in the middle of the Triassic valley between the subsequent Ouse working northwards and the other subsequent (the captor of the Tees) working southwards will have been accentuated.

The disjointed portions of the Ure, the Swale and the Tees had their energy increased, and they cut down into the peneplain. The obsequents grew in strength and lengthened themselves headwards, deepening at the same time the notches in the escarpment.

The arching up of the peneplain during the progress of the uplift went on concurrently with the deepening of the valleys of the original consequents. Thus the Esk sank its channel deep into the surface of the peneplain irrespective of the old folds in the strata of the platform, and therefore intercepted the passage and continuation northwards of all the secondary consequents which flowed down the northern slopes of the new moorland watershed. But on the northern side of the Esk valley the surface of the peneplain was also tilted by the same movement and a number of new secondary consequent streams were also initiated, following the slope of the ground and the general dip of the strata, but determined primarily by the slope of the ground. The pre-existing Hinderwell-Runswick original consequent which was at the same time revived intercepted a few of them.

These secondary consequent streams north of the Esk are, as previously mentioned, independent of the rolls in the strata in their general northerly or north-easterly course; and they are represented now by Borrowby Beck, by the valley holding the parallel Easington and Rousby Becks, by Kilton Beck, by the Boosbeck Valley and by Skelton Beck. Many of these valleys have been filled with Boulder Clay, and the streams diverted from their former channel; and the adjustments and captures effected subsequently by the streams (see *postea*) have made their original course less obvious.

The Mulgrave Valley holding now the Mickleby and Birk Head Becks probably represents the head of an original consequent of the first cycle revived by the later uplift. Perhaps this is the case also with the Hinderwell-Runswick Valley.

On the south side of the Esk the formation of the new watershed trending east and west and the general easterly tilt of the surface of the peneplain caused secondary consequents to arise and flow down its opposite slopes in northerly to north-easterly and southerly to south-easterly directions. The residual irregularities and unevenness of the peneplain caused minor deviations from these directions.

On the north side of the watershed were thus initiated Basedale and Westerdale Becks, Danby Beck, the two becks from Little and Great Fryup Dales, Glaisdale Beck, the beck from Egton Grange, the Murk Esk, Little Beck from Iburndale, and Rigg Mill Beck. From their initiation these secondary consequents were not all of equal strength, and as a result their valleys were excavated at different rates, and some grew headwards towards the watershed faster than others. Thus the Basedale Beck seems to have been always small and slow of growth, probably on account of its small gathering ground, while the Murk Esk rapidly cut down its channel and grew headwards to the watershed. The col separating its headwaters (Eller Beck) from those of the stream on the opposite side of the watershed was rapidly lowered, and as the Murk Esk grew much faster than its opponent and offered a shorter course to the sea at a lower level it abstracted the headwaters of this southern stream and shifted its own head backwards to Fen

Bogs in the other valley and south of the divide. Thus the two valleys falling in opposite directions were transformed into one continuous valley with the water-parting in the middle of its course but considerably south of the original line of watershed (3) (Fig. V.).

The upper portion of the Murk Esk which effected this capture and led away the water to the north is known as Eller Beck. The anti-dip stream, east of the point of capture at the head of Newtondale, is of later growth, and runs down from its source in May Moss which is 300 ft. higher than the head of the present Newtondale stream (Pickering Beck).

This curious case of diversion was first explained by Fox-Strangways (3).

The original course of the lower part of Eller Beck does not correspond with that of the present stream, the old pre-glacial valley being filled with Drift and lying west of the present narrow gorge near Darnholm.

The other head-stream of the Murk Esk is known as Wheeldale Beck and joins the Eller Beck at Beck Hole; and this stream also now rises south of the anticlinal axis, having cut its way back through the original line of watershed like its fellow.

It should be noticed that at the point where the Murk Esk enters the Esk, there is a wide bend southwards of the Esk valley, so that here the Esk was nearer the anticlinal axis than at any other place along its course. Therefore the secondary consequent—the Murk Esk—would from the first have the shortest and steepest course, and accordingly would sooner cut through the watershed (which first coincided with the anticlinal axis) than its fellows. Its long extension headwards and successful captures are thus explained.

With regard to Wheeldale Gill with its peculiar course to the east it may be suggested that it represents part of an old disjointed original consequent which was weakly revived on the uplifted peneplain but soon captured by the southward growth of the Murk Esk. The lower and eastern part of such a revived consequent may be sought for near Scalby where it would join the Derwent-Swale.

The development of the Esk valley as it sank into the

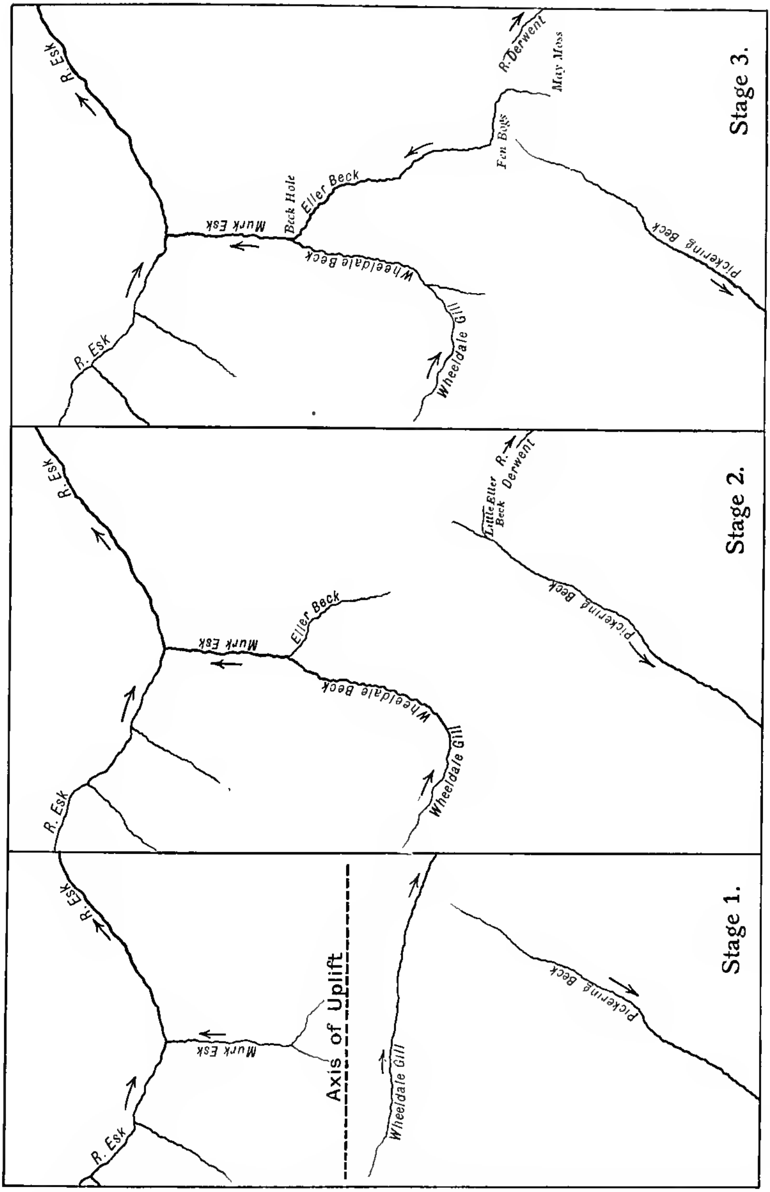

Fig. V. *Diagrams to illustrate captures effected by Murk Esk in pre-glacial times.*

surface of the old peneplain was likewise followed by the formation of some small affluents on its north side which entered it mostly as anti-dip-streams along the middle and lower portion of its course (*e.g.* Stonegate Beck). These would not be formed till the second cycle was somewhat advanced.

Near the head of the Esk also some small tributaries were formed, such as Sleddale Beck and Lonsdale Beck. Basedale Beck is probably also of this nature in its upper part, but the part from the mouth of Basedale to Scale Foot must have originated previously, as otherwise we should expect to find the Basedale and Westerdale valleys continued northwards into the main Kildale-Scale Foot valley of the Esk.

The easterly recession of the main Jurassic escarpment was proceeding steadily during the development of all these streams. The effect of the revived anticlinal uplift along the moorlands led to the formation of a deep embayment in its course around Ingleby Greenhow and to the increased width of the outcrop of the Lower Lias. North of Kildale the faulted outliers of Lower Oolite of Eston and Upleatham withstood the agents of denudation better than the Lias which bounded them, and thus formed a high promontory projecting into the plain of Lower Lias and Trias. From the heights surrounding these

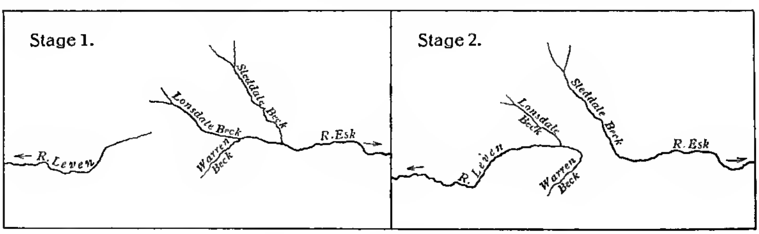

Fig. VI. *Diagram to illustrate the capture of tributary becks at head of River Esk by River Leven.*

two embayments flowed down numerous small streams which fell into the obsequent Leven.

The recession of the escarpments in these embayments towards the end of the second cycle reduced the gathering

grounds of some of the secondary consequents (*e.g.* Skelton Beck and Boosbeck on the north of the main watershed, and Hodge Beck and the river Seph on the south of it).

The headward growth of some of the streams in the embayments seem also shortly before the beginning of the next cycle to have effected some captures (*e.g.* the head of Skelton Beck south of Tockett's Mine).

The growth headwards of the obsequent Leven also resulted at this late period in the capture of Lonsdale Beck and Warren Beck which were the headwaters of the Esk on the north and south slopes of Kildale Gap (Fig. VI.).

At this stage, too, it is probable that the short obsequent Slape Wath Beck near Guisborough captured the headwaters of the Boosbeck stream, and was itself captured shortly afterwards by the easterly head-branch of the Skelton Beck. The north-easterly flowing stream from Eston Hill to Thornton Moor House (which perhaps was a small secondary consequent) was captured also by the western branch of Skelton Beck. Subsequent movements and accumulation of Glacial Drift, etc., have obscured these changes. Possibly the Slape Wath channel was not formed till post-glacial times.

We may now turn to the consideration of the secondary consequent streams started on the *south* side of the watershed in the second cycle.

With regard to the original consequents which were revived we probably see in the curiously independent and meandering course of the Troutsdale-Derwent-New Cut valley the representative of the lower portion of one which persisted and excavated a deep and wide valley in the surface of the peneplain. Possibly there was another revived consequent to the north of this which is represented by Wheeldale Gill and may have joined the New Cut consequent near Scalby; but from the investigation into the development of the Murk Esk we have seen it must have lost its head-waters at an early date in the second cycle. Such a consequent must have had its course along the north side of the Hackness synclinal, and as a result of the anticlinal uplift was converted into a strike-stream flowing along the foot of the Middle Oolite escarpment. But this is

more or less conjectural, and subsequent changes and adjustments, mostly of post-glacial origin, have interrupted its continuity and led away its waters in such different directions as to make it scarcely recognisable.

South of the Troutsdale-to-Scalby revived consequent there was the subsequent stream of late origin in the first cycle which had been developed on the Kimeridge Clay outcrop (p. 67). It is not probable that this stream attained large dimensions in the first cycle, but by the Miocene uplift, as well as by the general easterly tilt of the surface of the peneplain and by the axial uplift of the moorland its energy was much increased, and by pressing against its right bank it worked down the dip of the strata, and caused the Chalk escarpment to recede continually to the south. In fact it underwent a 'monoclinal shifting' (29) (26), widening its valley as well as deepening it, and it was assisted in the process by the Kimeridge Clay lying in a shallow synclinal trough.

At the same time the remains of the original consequent Ure east of Gilling Gap, which had been revived, were engaged in cutting down into the surface of the peneplain.

The dip of the Cretaceous beds along the present Wold escarpment from Malton southwards and their thickness show that they must have covered the Howardian Hills more or less completely at the beginning of this cycle, but probably at their north-western end near Gilling Gap the Oolitic rocks outcropped at the surface.

The descent and growth of the southerly-flowing secondary consequents from the moorland watershed at this westerly limit of the Cretaceous cover would rapidly cause the Chalk escarpment to retreat to the south-east. The Ure, reinforced by the waters of several of these secondary consequents, would quickly cut down to the Kimeridge Clay, over which it would meander in a slack reach above its entry into the Chalk outcrop. Thus west of its breach in the Cretaceous escarpment its valley would continually tend to be widened. The sub-Cretaceous platform of the Howardian Hills would be exposed, and the direction of the Ure would be guided to a large extent by the faults ranging along their northern flanks

and bringing the soft Kimeridge Clay against the much harder Middle Oolites.

The stripping off of the Cretaceous cover from the Howardian Hills must have gone on rapidly during the process of the elevation and deformation of the peneplain; and when the movement ceased the down-cutting of the river-channels would proceed at a greater rate than the lateral shifting of the escarpment. Before the land became stationary it appears that the subsequent stream flowing eastwards along the Kimeridge Clay syncline had grown considerably headwards and was receiving the drainage of all the eastern part of the southern slopes of the moorlands.

All the circumstances of its position had favoured its rapid growth headwards, and from the very initiation of the axial uplift of the peneplain and the resulting formation of the secondary consequents from the watershed which was thus originated it had intercepted the southerly course of these streams and led off their waters eastwards down the Vale of Pickering. By this accession of strength its channel had rapidly been reduced to low grade, and as a head-branch of it worked backwards along the foot of the Chalk escarpment it continually shifted its source westwards till at length it tapped the original consequent Ure, and at once led away all its waters between Gilling Gap and the Chalk escarpment. Thus the lower portion of the Ure east of this point lost all its supply, and its channel became a 'dry Chalk valley.' (Fig. VII.).

The successful stream which had effected this capture now had gained all the drainage of the southern portion of the Jurassic area. The Vale of Pickering was then soon reduced to base-level or nearly so, while the gap made by the Ure in the Chalk escarpment ceased to be deepened.

Where the Cretaceous escarpment crossed the Oolitic rocks of the Howardian Hills near Malton a stream draining the northern slopes of these hills would seem to have been formed, flowing down the general dip of the Oolitic beds into the Vale of Pickering and joining the stream which now drained it.

The capture of the Ure by the subsequent in the Vale of Pickering does not seem to have been effected till the western

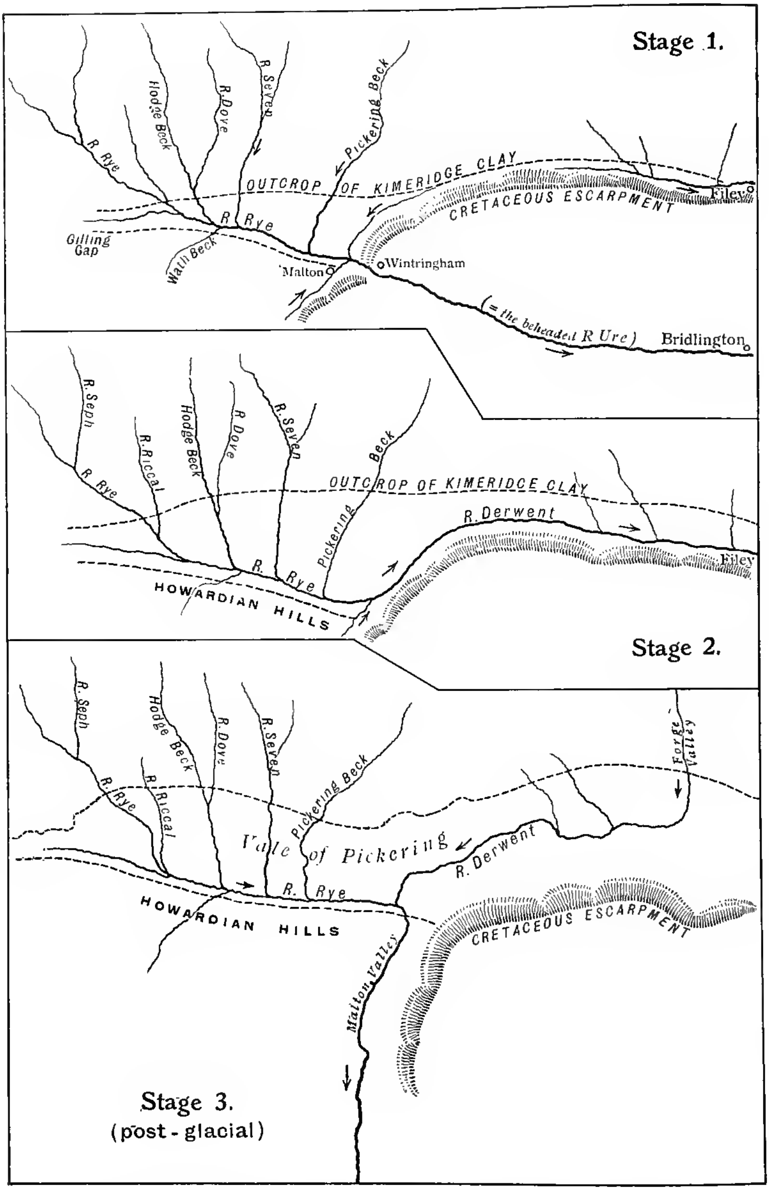

Fig. VII. *Diagrams to illustrate changes in drainage of Vale of Pickering.*

end of this valley had attained a considerable width owing to the meandering of the northern tributaries (the secondary consequents) of the Ure, for the mouth of the valley at Filey is comparatively narrow.

Moreover, since this successful Vale of Pickering stream does not appear to have widened the lower part of its valley even after its increase of volume, it may be concluded that the capture of the Ure by it did not take place till near the end of the second cycle; the Pliocene subsidence had begun, and all its lower course almost up to the present coast-line had been submerged. The advent then of glacial conditions completely stopped all river-work and subaerial sculpture by running water.

We must now turn back to consider the development of the secondary consequents on the southern slopes of the moorland axial uplift.

These rivers in their general direction follow the dip of the strata, but owing to the easterly inclination given to the peneplain as a whole they tend to flow rather more to the south-east than due south. At the western end of the Jurassic area where the strike of the beds curves round and the dip is strongly to the south-east or east the easterly trend of the secondary consequents is still more pronounced.

At the western end of the present Vale of Pickering the Kimeridge Clay was first exposed by denudation, as the Cretaceous was removed here while it yet extended over much of the eastern portion. The effect of the dip of the Jurassic strata coupled with the general easterly slope of the surface made itself first felt here by the streams. The river Rye is an example, and it is not improbable that even before the Miocene uplift it had come into existence as a short tributary of the beheaded Ure, but there is no clear evidence that it ever formed a continuous original consequent of importance, as Davis (1) has supposed.

The principal tributary of the Rye which issues from Bilsdale and is known as the Seph, is a true secondary consequent. The position of its sources on the edge of the Jurassic escarpment is merely a result of the subsequent recession of

the latter. Its tributaries as well as those of the Rye are likewise true dip-streams.

The upper branches of the Rye have not cut their channels so deep as the tributaries of the Seph because the axial uplift of the peneplain did not increase the dip of the beds over which the Rye flowed to such an extent, since their strike was beforehand to the south-west or south and their dip to the south-east or east.

Further east we find another true dip-stream, the Riccal, likewise a secondary consequent.

Next comes Hodge Beck of a similar nature and origin, from Bransdale, and to the east of it the river Dove from Farndale.

Beyond this to the east is Rosedale from which issues the river Seven.

The streams from all these dales cut through the escarpment of the Middle Oolites and through the Tabular Hills, and the character of their valley changes with their passage from one formation to the other.

Above this escarpment the direction of the three last-mentioned streams is consequent on the combined effect of the dip of the beds and the slope of the surface on which they originated; and this is also the case with the parts of Hodge Beck and the river Dove below the escarpment. But the river Seven from Rosedale cuts through the Tabular Hills in a due southerly direction and at right angles to the strike of the Middle Oolites. This seems to have been directly due to the change in the dip of the Middle Oolites east of Cropton and Sinnington—from a dip to the south to one to the south-west, as the Geological Survey maps show.

Between Farndale and Rosedale there are several short consequents cutting through the Tabular escarpment.

Turning now to topographic features, the formation of the east-and-west Jurassic escarpments proceeded concurrently with the development of the rivers and with the excavation of their channels in the surface of the arched peneplain.

The Kellaways Rock at the foot of the main escarpment of the Tabular Hills forms a marked 'step,' and where it is

strongly developed small subsequent streams are formed at its base, draining into the secondary consequents. Such is Sutherland Beck north of Cropton.

At the foot of the main escarpment on the Oxford Clay similar streams have arisen, as near Lastingham and Hutton-le-Hole.

We now come to the Pickering and Newtondale stream, the head of which was abstracted by the Eller Beck as we have seen (p. 71). The peculiar course of these streams from Fen Bogs to Pickering may have been partly due to some residual irregularities on the surface of the peneplain. At their initiation it is possible that the Cretaceous rocks may not have been completely denuded from this part. We may interpret Stape Beck and the portion of the Newtondale stream below it as far as Whinnymoor as a true secondary consequent with its direction determined by the same two factors as the others to the west. Below Whinnymoor some other factor must have entered in and caused the stream to bend to the south-west across the dip of the beds and against the general slope of the surface. The nature of this factor has been suggested above.

The upper portion of the stream above Stape Beck to Eifel Head is of the nature of a true subsequent and strike-stream at the foot of the escarpment of the Lower Calcareous Grit. Above Eifel Head to Fen Bogs the course of the stream, though in the main following the dip, seems to have been influenced by the roll in the beds in this neighbourhood.

The smaller true dip-streams on the Middle Oolites call for no special notice.

Thornton Dale and its branches have a curiously irregular course, but it is capable of explanation by the complicated outcrops of the beds induced by the synclinal axis running across Allerston Low Moor to the neighbourhood of Lockton and Levisham. The greater part of Staindale is in this synclinal, and the Thornton Dale stream on issuing from it becomes a true dip-stream till near its mouth it makes a bend to the south-west like the Pickering stream. That the Thornton and Staindale Becks had a late origin in the second cycle is suggested

by their close dependence on the minor folds of the Oolitic rocks, rather than on the general slope of the deformed pene-plain or main anticlinal, and probably the upper and lateral branches were not formed till nearly the end of this cycle after all the main features of the surface had been developed. Some may even be still later, for they bear the marks of youth.

The becks which arise on the surface of the Kellaways Rock, such as Grain Beck, Stockland Beck and Hipper Beck, are all late secondary consequents and are dependent for their direction on the local dip of the strata and the existence of the escarpment of the Tabular Hills. Black Beck along North Side is likewise a late subsequent.

The lower part of the Langdale stream may also possibly have been developed as a short secondary consequent in the second cycle; and all these streams flowed into the revived original consequent Troutsdale-Derwent-New Cut-Scalby river.

The stream composed of Helwath Beck and the lower part of Jugger Howe Beck must be regarded as a weak secondary consequent which did not prolong itself southwards over the Hackness outlier, because it was intercepted by the pre-existing and revived original consequent which flowed south-east to Scalby and was maintained by the strike of the Jurassic beds, so that it became in the second cycle a strike-stream at the foot of the escarpment of the Middle Oolites. It appears therefore that the Helwath and Jugger Howe Becks had their waters carried off to the south-east even in the second cycle.

The old valley which runs south-eastwards to Hayburn Wyke parallel to the coast and constitutes Staintondale may probably be regarded as having held a secondary consequent.

The curious manner in which the streams ramify over the Middle Oolites north of the village of Hackness is directly traceable to the varying dip of the beds produced by the synclinal structure of that outlier.

The small dip-streams between Thornton Dale village and Ayton are directly dependent for their direction on the dip of the beds over which they flow, and the same may be said of the Seamer Valley and Deep Dale streams near Scarborough. These were developed as the subsequent stream draining east

to Filey deepened and widened its valley in the Kimeridge Clay.

With regard to the course of all the secondary consequents when they entered the outcrop of the Kimeridge Clay, it appears probable that all those west of and including the Pickering stream (and perhaps the Thornton Dale stream) were at first tributaries of the old Ure between Gilling Gap and the Chalk escarpment. For the western portion of the Vale of Pickering was formed before the eastern by the removal of the Chalk and exposure of the Kimeridge Clay which then suffered rapid denudation (p. 76). When the subsequent stream entering the sea at Filey had worked back far enough headwards under the Chalk escarpment it abstracted all these, as previously described; but it had at first possessed as tributaries only the smaller dip-streams and secondary consequents from the eastern end of the moorland arch of the peneplain.

Turning now to the consideration of the streams in the great Triassic valley or Plain of York, we have seen that the subsequent Ouse was revived, and being fed by the affluent head-waters of the original consequents which it had beheaded, proceeded to deepen and widen its valley.

Several other strike-streams were developed in this valley and conducted the drainage of the face of the retreating Jurassic escarpment into the Ouse and Humber.

The river Wiske may be regarded as the growth headwards of the original Ouse; the sudden bend in the course of its anti-dip head-stream appears due to accumulations of Drift.

The anti-dip stream at the head of Cod Beck, which is another strike-stream on the Trias, seems to have formerly fallen into the Wiske but has been captured by the growth headwards and northwards of Cod Beck. The lower part of the latter has its course directed by the faulted outlier of Borrowby, along which it flows.

Numerous anti-dip streams from the escarpment are of pre-glacial age and were formed in the second cycle, as the infilling of their valleys by Boulder Clay indicates.

The origin of the obsequent stream from Gilling Gap which flows into the Ouse has been described. Its present weak condition

is principally due to changes wrought by the accumulation of Drift in Glacial times.

The river Foss is composed of an anti-dip stream from the Howardian Hills, of late origin in the second cycle, and of a secondary subsequent with its course modified by the deposition of Drift, etc.

The Derwent south of the Howardian Hills must be regarded as a subsequent at the foot of the Chalk escarpment originating in the second cycle and therefore before the whole Malton Gorge was excavated. Its head, however, even in this cycle was probably formed by an anti-dip stream from the Howardian Hills, like the Foss; and this anti-dip stream may well have marked out the line of the southern part of the gorge which was subsequently cut from the Vale of Pickering.

The river Foulness was, like the lower part of the Derwent, a secondary subsequent in the Triassic valley.

The principal rivers and streams of the second cycle have now been described in the foregoing pages, but we see that two important features in the present drainage were not then developed; (i) the Forge Valley and the consequent desertion of the New Cut valley, and (ii) the reversal of the drainage of the Vale of Pickering and the formation of the Malton Gorge through which it now escapes.

In nearly every other respect the system of rivers was the same as that now existing. A few valleys have been filled up, a few minor streams diverted, and a few adjustments produced, but apart from the two above-mentioned important alterations, the changes have been trifling; and it is generally acknowledged that all the main characteristics of the topography had been developed before the advent of the Glacial Period.

The traces of the effects of the subsidence which characterised the third cycle are not very marked so far as the rivers are concerned. The North Sea was formed by this depression, and the lower portions of the rivers were submerged. The whole land was brought nearer base-level, and accordingly the downward corrasion of the rivers was checked.

If the old raised cliff near Bridlington (p. 16) marks the margin of the sea at this date, it is evident that the general

level of the land was considerably lower than it is now. The Vale of Pickering at this time became an arm of the sea, and perhaps some part of the Vale of York was also flooded. The valleys excavated in the previous cycle were depressed about 100 ft. below the present sea-level, as borings in the Esk Valley, Vale of York, Vale of Pickering, Humber and valleys of streams north of the Esk have shown. These submerged valleys were filled with Drift during the succeeding Ice Age.

In the Ice Age most of the region was covered by the glaciers, but the centre of the Jurassic area, as before stated, seems to have stood up above them. Some of the dales had their lower ends so blocked with ice that lakes were formed in them of the same nature as the Marjelen See. It is extremely doubtful if any of the pre-existing valleys were deepened by the passage of the ice along them, and the hypothetical excavating power of these glaciers has never been estimated. It would lead us too far away from our subject to enter into this highly controversial question.

The retreat of the ice left an irregular sheet of Drift over a great part of the country. Many of the old valleys were more or less filled up with it, and almost obliterated; others had their mouths blocked with it, and temporary lakes formed[1]. The chief effect of such lakes is to lead to the formation of new outlets for the drainage of the valleys in which they lie. The water escapes over the lowest point of the surrounding heights, and this point frequently does not correspond with the former point of outflow. The new outlet is then cut down till the lake is drained, or till the dam at the mouth of the valley is removed. The location and depth of the overflow channel mark the position and height of the dam; and its duration, or rather the length of time during which the lake lasted, can sometimes be judged by the same criterion, or by the terraces it has left on the sides of the valleys. The present author's observations of the traces of these lakes

[1] Mr P. F. Kendall is at present making the traces of such lakes a special study, and until the results of his work are published we cannot apply them to the present subject of enquiry, but they will probably throw considerable light on the post-glacial changes in the drainage.

are given here only so far as they bear on the important alterations in the drainage above mentioned.

The Vale of Pickering offers the most remarkable example of the effects of a glacial dam. The huge deposit of Drift which had been spread all along the coast in a broad band by the passage of the ice southwards (18) completely blocked up the end of the valley in Filey Bay and extended two or three miles up the Vale of Pickering. This great barrier entirely prevented the drainage of the valley being led away in an easterly direction into Filey Bay as heretofore; and the water finding its exit blocked here was wholly dammed back, converting the Vale into an immense lake which continued to receive the supply from the streams on the north and west. The level of the lake was gradually raised as the basin filled up, until an outlet of escape was reached. This outlet was found over the Howardian Hills by Malton, where a short dip-stream had cut a valley in the Middle Oölites in its passage down into the Vale of Pickering, while on the southern side of the hills the anti-dip head of the subsequent Derwent flowing along the Triassic plain (p. 84) had likewise carved out a small valley prior to the Glacial Period. Over the col between the heads of these two opposing streams (situated probably between Cram Beck Bridge and Crambe) the pent-up waters of the lake escaped, and rapidly cut down the barrier so as to form a narrow gorge. The side-streams from the face of the Chalk escarpment and from the Oolitic rocks on the other side of the valley (which had their course in some cases determined by the position of the faults) now all became tributaries of the greatly enlarged Derwent.

After the lake was drained the whole group of rivers which flowed down into the Vale of Pickering and consisted of portions of original consequents, of original subsequents, of obsequents, and of complete secondary consequents, sent their waters through this Malton Gorge into the subsequent Derwent in the Vale of York, and so into the original consequent Aire-Humber (see Fig. VII., p. 78).

It is not necessary to consider that the height of the col over which the waters escaped was the same as the present height of the escarpment of the Howardian Hills at Kirkham which is

stated (3) to be between 200 and 250 ft., for the anti-dip head of the Derwent on the south side had previously notched it.

The curious curve in the course of the valley between Low Hutton and Crambe does not resemble the sort of channel which we should expect would be marked out by a sudden overflow from a lake. The geological structure does not seem to offer any obstacle to a much straighter and more direct course past Westow. It seems, however, to have been the case that the Cram Beck and the continuation eastwards of its valley to the point where it makes the bend northwards existed prior to the formation of the lake as the head-tributary of the dip-stream running down to Malton to join the Rye. The position of the col, therefore, was probably near Castle Howard Station, and the bend to the east which the overflow stream made after crossing the col may very well have been caused by the great mass of Boulder Clay on the hills between Whitwell and Crambe turning it out of its more direct course. There is no sign that this portion of the valley is pre-glacial; in fact, all the evidence points the other way.

The tests which are most readily applicable to decide the pre- or post-glacial age of a valley or gorge in this area are derived from local evidence. If a valley is wide with more or less flaring sides and all angularities worn off, and if the Glacial Drift lies along its floor or sides, it was excavated before the Ice Age. If, on the other hand, it is narrow with more or less precipitous sides showing no sign of glaciation, and if no Boulder Clay is found in it and the contour of the surrounding ground shows that the Glacial Drift in the vicinity was deposited without any reference to its existence, the presumption is that it is post-glacial.

In the case of districts which we have reason to suppose were not traversed by the ice in the Glacial Period, it is difficult to fix the age of such gorges. But the characters of youth are generally sufficiently distinct to distinguish post-glacial gorges, while the relations to the neighbouring water-courses are also of assistance.

If the col over the Howardian Hills had not been lower than that which existed at Gilling Gap, the lake would have used the

latter as its outlet. But this gap had been almost filled up with Boulder Clay, forced up by the ice in its passage down the Vale of York, and at the present day Boulder Clay occurs in the Gap at a height of 279 ft. The obsequent stream running westwards from this gap had had its course almost blotted out by the mass of Drift in the Triassic plain, and the feeble channel of the present Elphin Beck shows how little it has succeeded in re-establishing itself even after the long lapse of time since its revival on the Drift-covered surface.

At the east end of the Vale of Pickering the top of the barrier of Boulder Clay stands now at a height of only 130 feet above sea-level. Now this height is not sufficient to have reversed the drainage and to have turned it over the col at Malton, unless the latter was still lower, which is scarcely probable. The Filey dam, whether of ice or Drift, must therefore have originally been considerably higher, and if it did not partly or wholly consist of ice its present low level must be due to denudation or depression. It is probable that the coast has here suffered very much from marine erosion, and that when it extended further eastward the height of the barrier was greater. The Boulder Clay has also suffered considerably from subaerial denudation; and it is not improbable that the later coastal depressions marked by the buried forests may have still further reduced its height. The original enormous thickness of the Boulder Clay which may have existed at this point can thus be approximately estimated.

Traces of the shore-lines of the lake are seen in the terraces of gravel near Hutton Bushel on the north side of the Vale of Pickering. The highest of these is at a level of 225 ft. (12), and, according to Fox Strangways (3), would correspond with the level at which a beach would be formed when the lake had risen to the level of the col at Malton. The two minor terraces below this at levels of 140 ft. and 100 ft. are thought to mark stages when the denudation of the Malton Gorge was checked.

The second important example of the effects of a dam of glacial origin on the drainage is found in the case of the Troutsdale-Derwent-New Cut-Scalby stream. (Fig. VIII.) This stream had the mouth of its valley completely blocked

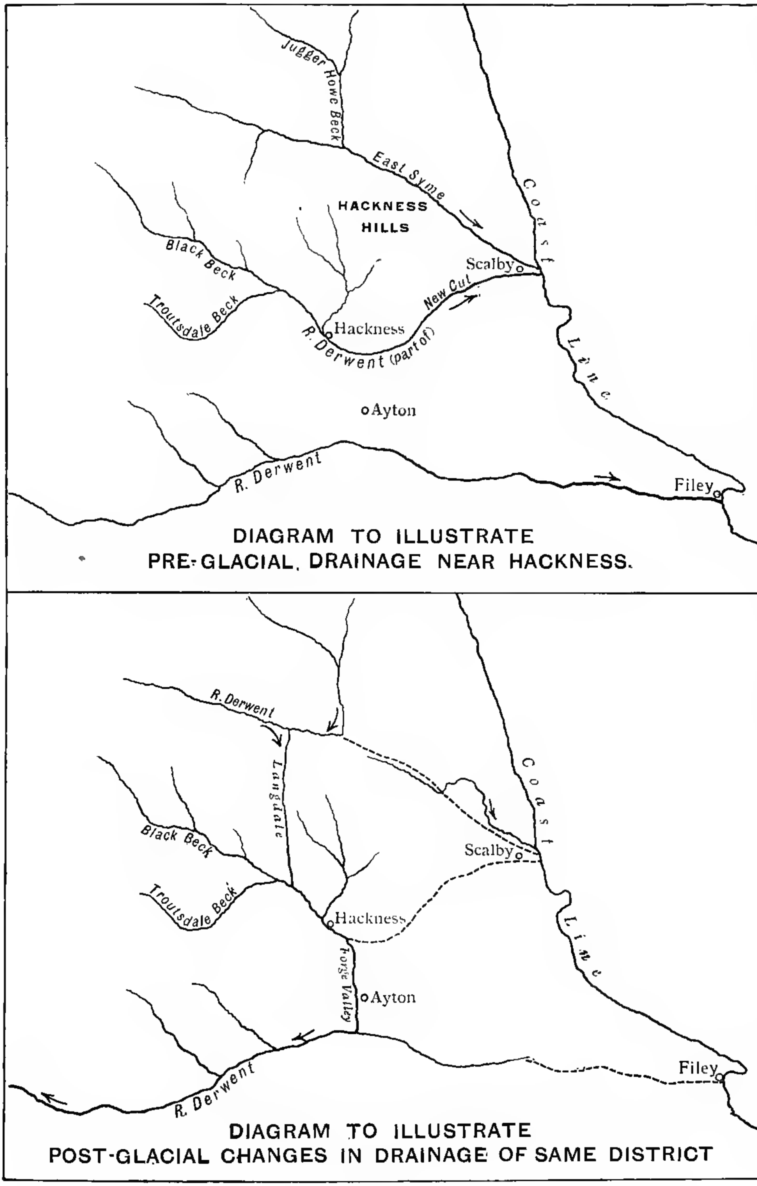

DIAGRAM TO ILLUSTRATE
PRE-GLACIAL DRAINAGE NEAR HACKNESS.

DIAGRAM TO ILLUSTRATE
POST-GLACIAL CHANGES IN DRAINAGE OF SAME DISTRICT

Fig. VIII.

by a mass of Drift forced up against the eastern escarpment of the Tabular Hills. Its whole valley was converted into a lake by this obstacle to the escape of the water, and the lake thus formed rose till it reached a level at which it could find an outlet. Such a passage of escape was found over the narrow part of the Tabular Hills along the line of the Forge Valley. This valley answers satisfactorily to the tests for a post-glacial origin, and accordingly may be regarded as having been cut out by the overflow water of the above-mentioned lake. The continued deepening of this channel eventually drained the lake, and the waters of the Troutsdale-Scalby river with its tributaries were conducted by this means into the Vale of Pickering, and so ultimately into the Vale of York through the Malton Gorge.

Another example of damming is found in the immediate vicinity of the above-mentioned case. The long stream which flowed along the northern foot of the Hackness escarpment and entered the sea near Scalby, receiving on its way Jugger Howe Beck, was turned back in a similar way by the huge mass of Drift near its mouth (Fig. VIII.). The upper portion of its valley was turned into a lake, which found an overflow channel along the line of Langdale into the New Cut lake in the same manner as the latter did into the Vale of Pickering by the Forge Valley. It is possible that a small dip-stream may previously have existed in the lower part of Langdale, or more probably an anti-dip stream at the north end of the dale, since this portion of the valley widens northwards.

The dam of Drift which effected this reversion of drainage extended right up the original valley to the point where it received Jugger Howe Beck. Lindhead Beck and Burniston Beck which now drain down to Scalby are streams of late origin initiated on the surface of the Drift, but more or less closely following the general line of the old pre-glacial river.

The bed of the New Cut pre-glacial river is found by borings to be many feet below sea-level at Scalby, and the same is the case with all the rivers along the coast whose pre-glacial valleys have been sounded by borings. Thus in addition to those already mentioned the valleys of the Esk,

Skelton Beck, and the Tees have been proved to be from 80 to 100 ft. below present sea-level near their mouths (8) (10).

Minor deviations from the pre-glacial channels in these old valleys have been caused in many cases by a local infilling of Boulder Clay (3) (8).

Thus the Esk immediately above Egton Bridge now flows in a gorge between East Arnecliffe and Limber Hill Woods, but the old valley is on the north side of Limber Hill and is blocked with Drift (10). A new gorge at Crankly Gill is only 150 yards across (10), while the old valley is as much as three-quarters of a mile in width. The present valley of the Esk below Ruswarp to its mouth at Whitby is also a narrow post-glacial gorge; the old valley turned to the north near Ruswarp and entered the sea north of Whitby (3).

The alteration in the course of the Murk Esk is likewise most noticeable. The narrow rocky gorge by Darnholm is of post-glacial origin, the old valley having had a more direct course to Beck Hole along the line of the old inclined railway (3). The Wheeldale branch of the Murk Esk has likewise been diverted from its old channel by the Drift, and has cut out a similar narrow gorge behind Goathland.

The narrow ravine down which the Staithes Beck escapes to the sea is also post-glacial. The Easington and Rousby Becks which previously turned down the Hinderwell valley to Runswick Bay found this blocked up completely by the Drift, and accordingly escaped by the shortest and most direct course to the sea at Staithes which this gorge represents.

The gorge of the Leven in Kildale south of Easby Moor may also be mentioned as an example of a post-glacial channel cut by a revived stream, the old valley which lies to the south being entirely filled with gravel, etc.

Skelton Beck and Kilton Beck have likewise cut new channels in the solid rock alongside of their old valleys (8).

A curious feature in several of such Drift-filled valleys is the presence of two parallel streams down a great part of their course (3). The old valley in pre-glacial times held only a single stream, but the new streams have originated along the lines of weakness where the Boulder Clay rests against the rocky

sides of the old valley. A ridge of Drift is thus left separating the two present streams, though in some cases this has been nearly denuded away. Examples of such parallel streams are found (i) in those flowing past Mulgrave Castle and entering the sea at Sandsend along the valley of the upper portion of an original consequent (see p. 40); (ii) in the Rigg Mill Beck Valley near Whitby; and (iii) in the Easington and Rousby Becks above Staithes.

It may be remarked with reference to the narrowness and depth of the post-glacial gorges, which have been thought to demand some special and violent process of formation (32), that the depth and width of a valley depend not only on the elevation of the land above sea-level, but also (i) on the original gradient of the surface over which the stream flowed; (ii) on the ratio of stream corrasion to the general waste of the bordering lands; and (iii) on the character and hardness of the rocks traversed. When the rocks are hard, the gradient steep, and the ratio of stream corrasion in marked excess of the rate at which the general surface of the ground is being lowered, narrow deep valleys will be produced, such as these post-glacial gorges.

Streams which were revived on the Drift-covered surface with low gradients have developed an irregular meandering course between the hummocks and ridges of Glacial material, and frequently deviate considerably from their pre-glacial channels. The streams traversing the Vale of York furnish excellent instances.

It is probable that the raised beach at Saltburn marks a slight depression of the land taking place during and probably towards the end of the fourth river-cycle (p. 32). If the land when the ice departed stood approximately at the same level as it now does, the extent of the subsidence did not exceed 30 ft.—the height at which the raised beach occurs. The effect on the growth of the rivers is not perceptible.

The fifth cycle was marked by an elevation of the land (or at least of the sea-margin) to a slightly higher level than that at which it now stands, for to the present height of the raised beach above the sea must be added the amount lost in the

following cycle by the subsidences proved by the "buried forests."

The sixth cycle was characterised by depressions interrupted by intervals during which the land remained stationary. The forest-clad sea-margins and river-banks were submerged, and inland lakes were formed near York (7). Probably some of the alluvial deposits of the Vale of Pickering also date back to this period. These downward movements produced the "buried forests" and brought the land to its present level. Their general effect on the rivers was to check their development and the downward corrasion of their channels, but it is not part of the subject of this Essay to trace their effects in detail.

From the almost imperceptible effects of the movements of the fifth and sixth cycles on the drainage system it seems that the period over which they extended was short compared with that in which the main features of the river-system were developed. The modern character of the fauna of the raised beach at Saltburn bears this out.

CHAPTER VI.

CONCLUSION.

By the preceding examination of the geological and physical evidence we have traced the general outlines of the evolution of the present drainage-system of East Yorkshire through several successive stages, and we find that its history is intimately bound up with that of the whole of Eastern England since Palæozoic times. There are local details still waiting to be filled in, and branches of the subject still to be investigated, but it is believed that they will produce no evidence which will contradict the main results here worked out. The division of the physical history of the region since Cretaceous times into six stages or cycles is based on geological evidence which is practically incontrovertible; the assumptions as to the original slope of the surface and the deformation of the peneplain are supported by orographical measurements and geotectonic considerations of great weight, as well as by being in harmony with evidence from other parts of England; and, finally, the theory of consequent and subsequent streams has been established on a firm foundation by Davis and many other workers in the same field. The hypothesis of the secondary origin of the Moorland anticlinal as a watershed more or less parallel to the original consequent streams has been found to afford a natural and satisfactory explanation of the behaviour and characters of the water-courses which it concerns; and the modifications effected by the Glacial Period have been interpreted in most cases from direct field-evidence.

LIST OF WORKS REFERRED TO IN THE TEXT.

Reference Nos.

(1) **Prof. W. M. Davis,** The Development of certain English Rivers. (*Geographical Journal,* vol. v., pp. 127—146. 1895.)

(2) **Prof. J. Phillips,** The Rivers, Mountains and Sea Coast of Yorkshire. (London, 1853.)

(3) **C. Fox-Strangways,** The Valleys of North-East Yorkshire and their Mode of Formation. (*Trans. Leicester Lit. Phil. Soc.,* New Series, vol. iii., part vii., pp. 333—344. 1894.)

(4) **C. Fox-Strangways,** The Jurassic Rocks of Great Britain. (*Mem. Geol. Surv.,* vol. i. 1892.)

(5) **H. B. Woodward,** The Geology of England and Wales. (2nd Ed.) (London, 1887.)

(6) **W. H. Hudleston,** The Yorkshire Oolites, Part I. (*Proc. Geol. Assoc.,* vol. iii., p. 283. 1873.)

(7) **C. Fox-Strangways,** The Geology of the Country North-East of York. (*Mem. Geol. Surv.,* Quart. Sh. 93, N.E. 1884.)

(8) **G. Barrow,** The Geology of North Cleveland. (*Mem. Geol. Surv.,* Quart. Sh. 104, S.W., S.E. 1888.)

(9) **C. Fox-Strangways and G. Barrow,** The Geology of the country between Whitby and Scarborough. (*Mem. Geol. Surv.,* Quart. Sh. 95, N.W. 1882.)

(10) **C. Fox-Strangways, C. Reid, and G. Barrow,** The Geology of Eskdale, Rosedale, etc. (*Mem. Geol. Surv.,* Quart. Sh. 96, N.E. 1885.)

(11) **C. Fox-Strangways, A. G. Cameron and G. Barrow,** The Geology of the country around Northallerton and Thirsk. (*Mem. Geol. Surv.,* Quart. Sh. 96, N.W., and 96, S.W. 1886.)

(12) **C. Fox-Strangways,** The Geology of the Oolitic and Cretaceous Rocks south of Scarborough. (*Mem. Geol. Surv.,* Quart. Sh. 95, S.W., and 95, S.E. 1880.)

(13) **C. Fox-Strangways,** The Oolitic and Liassic Rocks to the North and West of Malton. (*Mem. Geol. Surv.,* Quart. Sh., 96, S.E. 1881.)

(14) **C. Fox-Strangways,** The Geology of the Country North-East of York, and South of Malton. (*Mem. Geol. Surv.*, Quart. Sh. 93, N.E. 1884.)

(15) **C. Reid,** The Geology of Holderness. (*Mem. Geol. Surv.* 1885.)

(16) **J. R. Dakyns and C. Fox-Strangways,** The Geology of Bridlington Bay. (*Mem. Geol. Surv.*, Qt. Sh. 94, N.E. 1885.)

(17) **Prof. Carvill Lewis,** The Glacial Geology of England and Wales, p. 56, Map IV. (London, 1894.)

(18) **P. F. Kendall,** The Glaciation of Yorkshire. (*Proc. Yorks. Geol. Polyt. Soc.*, vol. ix., pp. 306—318. 1891.)

(19) **J. E. Clarke,** On Glacial Sections at York. (*Proc. Yorks. Geol. Polyt. Soc.*, vol. vii., p. 421. 1881.)

(20) **J. R. Dakyns, C. Fox-Strangways and A. C. G. Cameron,** The Geology of the country between York and Hull. (*Mem. Geol. Surv.*, Quart. Sh. 94, S.W., and part of 86. 1886.)

(21) **A. J. Jukes Browne,** The Building of the British Isles. (London, 1888.)

(22) **Prof. I. C. Russell,** River Development. (London, 1898.)

(23) **Baron von Richthofen,** Führer für Forschungsreisende. (Berlin, 1886.)

(24) **G. K. Gilbert,** Geology of the Henry Mountains. (2nd ed.) (*U. S. Geol. Surv.*, Washington, 1880.)

(25) **Prof. W. M. Davis,** The Rivers and Valleys of Pennsylvania. (*Nat. Geogr. Mag.*, vol. i., No. 3, pp. 1—71. 1889.)

(26) **Prof. De Lapparent,** Leçons de Géographie Physique. (Paris, 1896.)

(27) **S. S. Buckman,** The Development of Rivers. (*Natural Science*, vol. xiv., pp. 273—290. 1899.)

(28) **Prof. A. C. Ramsay,** Physical Geology and Geography of Great Britain. (6th ed.) (London, 1894.)

(29) **G. de la Noe et E. de Margerie,** Les Formes du Terrain. (Service Geogr. de l'Armée. Paris, 1888.)

(30) **C. E. De Rance,** The Water Supply of England and Wales. (London, 1882.)

(31) **A. Philippson,** Studien über Wasserscheiden. (Veröffentl. vom Ver. f. Erdkunde zu Leipzig, 1886.)

(32) **Prof. J. F. Blake,** The Geology of East Yorkshire. (*Proc. Yorks. Geol. Polyt. Soc.*, vol. vii., pp. 15—29. 1878.)

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